

ELECTRICITY AND MAN

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ЭЛЕКТРИЧЕСТВО
И ЧЕЛОВЕК
(лечение и опасность)

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Electricity and Man

(Medical application and hazards)

V. MANOILOV

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TO THE ENGLISH READER

This book was published in Russian several years ago. Since then much has changed; important discoveries have been made in electrophysiology. Development of the knowledge of electricity and its practical application has been broad and diversified, particularly its application in electronics, electrochemistry and power engineering. Conceptions have greatly altered and new interpretations have appeared. It is now obvious that at the elementary particle level, electricity is much more significant than was formerly supposed. The nonuniform concentration of electrons in a semiconductor, for instance, provides interesting knowledge of macroprocesses, making them a new type of primary transducers of information. Moreover, a change in the interdirection of the elementary particles in the atom imparts new properties to molecules.

Consequently some principles should undoubtedly be set forth differently, but after rereading the book I have come to the conclusion that what is of greater importance is not outdated. And the important thing is that knowledge of electricity in man is of the greatest significance and as yet constitutes a vast realm of the unexplored.

The more we know about electricity in man, the more successful we shall be in solving practical problems in its application. I therefore consider myself fully justified in leaving the basic content of the book without substantial revision. The experience of many years observation in man is not obsolete, has not lost its importance.

At the beginning of the 19th century electrophysiology and electrical engineering developed in different directions, but in time the two will merge into a single science of electricity.

BY WAY OF PREFACE

Luigi Galvani who discovered “animal electricity” at the end of the 18th century, and Niels Bohr who proposed a planetary model of the atom at the beginning of the 20th century can hardly have realised that their discoveries would not only mark the beginning of the extensive and increasing application of electricity but would also serve as the basis for solving the greatest mystery of nature—where does life begin? Where is the dividing line between the animate and the inanimate?

Electricity and man. Electricity has become a part of man’s life, changing the conditions in which he lives and works. One could cite a great diversity of examples of the use of electricity in industry, transport and communications, in the home, in medicine and art. Electricity has made it possible to develop new technology and to manufacture materials not existing in nature. The electromobile, replacing the automobile, is the future individual means of transport. Electrostimulators and other electrical instruments are today irreplaceable aids to the physician. Everyday life is being revolutionized.

But those are not the things our book deals with, although the development of electrification unquestionably gave grounds for writing it. The following examples will give an idea of what it is about.

A patient’s head shakes and is bent to one side; his hands tremble. He is completely incapacitated by a progressive disease of the nervous system. Drugs give little relief. The physician seats the patient in a chair and places electrodes in the form of small silvered plates on his temples, securing them with ordinary sticking plaster. He connects the electrode wires to a small pulse source of electric current and presses a button. Current from the electrodes passes through the

patient's body. The hands stop trembling and the head stops shaking. The patient can easily turn his head and his eyes light up with the hope of recovery. Thus begins his lengthy but promising treatment.

Or another example. A large well-lighted operating room. For over an hour surgeons have been performing a most delicate operation—an operation the patient must have if his life is to be saved. Suddenly the instrument registering the patient's pulse by the heart's electric activity shows that the heart is not working normally—numerous sharp spikes appear instead of the waves characteristic of the heart's normal condition. The heart has been unable to withstand the strain of the enervating disease and "fibrillation" has set in—the heart has ceased to contract rhythmically as a single whole. Instead, there is an uncoordinated jerking of the countless fibres of the heart muscle, recorded by the instrument as disorderly weak electric impulses. Their number reaches a hundred per minute. Such a fibrillating heart cannot force the blood through the vessels. It is as though the heart had stopped beating. The human heart, unlike that of an animal, say a dog, cannot spontaneously come out of the condition of fibrillation. Defibrillation measures must be taken at once or the patient will die. The physician places two metal plates on the patient's body as electrodes and secures them tightly against the skin. The wires from the electrodes are connected to an electric defibrillator. The physician presses the button and a sudden electric impulse of several thousand volts passes through the patient's body. The instrument recording cardiac activity shows that fibrillation has ceased. The heart begins to contract, at first weakly but then more vigorously, its activity gradually returning to normal.

But tragedies sometimes occur. A certain woman liked to sew for herself and her children. Her new electric sewing machine stood at a window, below which was the pipe of the hot-water heating system. It was her habit, while sewing, to put her feet in house-slippers on the warm pipe. Once she

kicked off her slippers and put her bare feet on the pipe at a spot where the paint was off, following some repair work. Without a sound she slumped over the machine, and all attempts to bring her back to life were futile. An investigation revealed that the insulation of one of the wires from the motor was defective where it was in contact with the steel frame of the machine. The tension was 127 V.

It is difficult to detect such faults and consequently the Regulations* prohibit the positioning of electrical appliances (which include electric sewing machines) near water and heating pipes.

Here we have two diametrically opposed effects: electricity can be used for treating disease, for saving lives, and electricity can cause death.

Life on Earth originated and developed in interaction with electromagnetic fields. Electricity is inherent in the living in its most complicated form—the vital activity of man.

Scientists have done much in studying this amazing interaction of electricity and the animate but much in nature is still concealed, much must be analyzed and understood.

This book will help to widen the reader's understanding of the interaction of electricity and the living organism, although it makes no claim to exhaust the subject.

* Safety-Engineering Regulations for the Operation and Maintenance of Electric Installations and Safety-Engineering Regulations for Household Electric Installations. Moscow, 1969.

Part One

ELECTRICITY CURES

CHAPTER ONE

Electrophysics of Inanimate Nature

1. MOTION, MOTION, MOTION...

Continuous, never-ceasing motion: changes and transformations of matter and energy—matter into energy, and energy into matter—this is what characterises nature. The diversity of the forms and types of motion and transformations of animate nature, particularly as regards man, is marked by great complexity. Every form of transformation and motion reflects an electrical phenomenon, either directly or indirectly, and is often caused by it. Movement of electric charge carriers is accompanied by the transfer of matter and a change in its properties and characteristics. A lightning discharge can cause serious destruction and kill both people and animals; at the same time the survival rate of newly-hatched chicks held in a high-voltage electrostatic field is higher than that of chicks not held in an electric field. Directly, an electric field can promote metabolic processes in animals and man, while indirectly, an electric field, as regards the favourable aspect, can bring about changes in the microflora of man's environment and through these changes favourably act on his body.

The interaction of the electricity of the environment and the electricity within the living organism depends on its electrical characteristics, one of the principal characteristics being electrical conductivity, which determines the movement of the charge carriers, their type and nature. Electric conduction is classified into the following types: electronic, ionic, semiconductor and plasmatic.

Electronic conduction is found in metals and other substances with close packing, which makes it possible for the electric field of an atom to "serve" several atomic nuclei, that is, to overheat them. Electronic conduction is also found in the upper layers of the atmosphere in which the density of matter is low and electrons can move freely without entering an electric field of different polarity.

Ionic conduction occurs in liquid electrolytes. Ions are charge carriers and during their movement transfer matter, changing the chemical composition of the electrolyte liquid under the action of the field.

Semiconductor conduction is characteristic of the largest class of substances. It consists in the directed movement of electrons from one substance to another, from one atom to another, if there is a vacancy, a "hole", into which the electrons rush.

Plasmatic conduction is due to the nature of plasma. Plasma is understood to be a gas containing a large concentration of charge carriers—substantially exceeding the number of uncharged elementary particles.

Quite a large number of substances belong to the class of insulators. In these substances all the charge carriers are firmly held by inner electrostatic bonds, and only a small part are capable of migration.

Electrical conductivity is assessed by the value of the reciprocal of the product, ohm metre. The numerical values range from $10^6 - 10^8$ 1/ohm m (for metals and plasma) to $10^{-12} - 10^{-16}$ 1/ohm m (for dielectrics).

Another most important electric property is dielectric

strength, especially for insulators, since their quality is primarily assessed by this.

The dielectric strength of a substance is defined as the maximum voltage which can be applied to a given material, object or the human body without causing a sudden rush of the charge carriers. This is termed the break-down of the material in question and the voltage causing it is termed the break-down strength. For human skin this value is 200 V/mm².

Investigations carried out in the 1960's and 1970's revealed that previous views concerning electrical conduction and dielectric strength were erroneous. For instance, it was thought that metals possessed only electronic conduction, and consequently the movement of the charge carriers was not accompanied by the transference of matter. It has now been found that such transference, though small, does take place through ionic conduction. It was held that there could be no electronic conduction in solutions. It now turns out that along with the movement of ions in solutions there is also movement of electrons which influence processes taking place in the solutions. Practically speaking, for any complex substance, for any state and for any environment, all types of conduction and electrical strength are present. This is particularly true of the living organism. Combined electric conduction in man is especially complicated.

2. ELECTRIC CONDUCTION IN METALS

Quite recently atoms were thought to be the ultimate "bricks" making up everything animate and inanimate (Greek *atomos* = indivisible). Now the conception of an indivisible atom has given way to the conception of an atom as complex system of particles with its own laws and relationships. The particles making up the atom include electrons, which are incomparably lighter and possess a constant electric charge. According to the modern view all electrons are identical—the electron in the hydrogen atom is exactly the same as the

electron in the uranium atom. The electron has a mass which is about $1/2000$ that of the hydrogen atom. It has a charge of 1.6×10^{-19} coulomb, the unit of electricity. Yakov Frenkel, outstanding 20th century Soviet physicist, said this about the electric charge: "To get an idea about the size of the electric charges bound up in matter it should be noted that if we were able to extract an electron from every atom of hydrogen in 1 g of the gas we would obtain a negative charge equal, in absolute electric units, to the product of 5×10^{-10} times 6×10^{23} , i.e., 3×10^{14} cgs units or 10^5 coulombs. The force of attraction between this charge and the total positive charge of the atoms of 1 g of hydrogen that have lost their electrons would come to approximately 10^{20} tons at a distance of 1 cm (over a million million tons! — *V.M.*). Taking into account the fact that electric forces diminish in inverse proportion to the square of the distance, it can easily be calculated that the force of attraction between these charges at a distance equal to the earth's diameter (about 13,000 km) would decrease 10^{19} times but would still be equal to 10 tons."*

Electrons are at a distance of a tenmilliardth of a centimetre from the nucleus, the centre of the atom. An electron is attracted to the nucleus with a force equal to 2.5×10^2 N/m². Such a force for a particle having such a mass as the electron is tremendous. The bond between the electron and the atom is characterized by the work that must be done to remove the electron from its initial position. The energy expended in removing the electron is equal to the energy of the bond between the electron and the nucleus. The energy of the bond or the potential is within the range of 1 to 30 eV.

Metals only conduct electricity when they are in the solid or liquid state, conduction being better in the solid state. If metals are heated to a temperature at which they are converted into vapour, or, in other words, go into the gaseous state, they

* Frenkel, Ya. I., *Printsipy teorii atomnykh yader* (Principles of the Theory of Atomic Nuclei), Moscow — Leningrad, 1955, p. 11.

cease to be conductors of electricity and the exchange of electrons stops. In the gaseous state metals behave the same as non-metals—insulators (dielectrics).

How is the appearance of electric conduction when metal vapour condenses to be explained? Here again Yakov Frenkel gives an excellent explanation: "The appearance of electric conduction when metal vapour condenses to a solid or liquid body is due to a phenomenon which can be called the 'deindividualization' of electrons, i.e., the loss by some electrons of their bonds with individual atoms".

Deindividualized atoms are capable of freely passing over from one atom to another. To put it more exactly, the bond of some electrons attracted by the positively charged nucleus of the atom is weakened and the electrons move about among the atoms without altering the chemical properties of the metal, since the number of electrons about each atom does not change. The freely moving electrons impart to the metal the ability to conduct electric current.

Why is it that metals, especially such metals as copper, silver and gold, have deindividualized electrons which easily leave the individual atom?

The electrons in an atom move round the nucleus in definite shells. The energy of the electrons in different shells differs by great values, depending on their mean distances from the nucleus. Within each shell the difference in energies is not great and is determined by the shape of the shell and its orientation in space, as well as the orientation of the electron's magnetic moment relative to the shell.

In 1925 the Italian physicist, Pauli, formulated the exclusion principle, according to which there cannot be more than one electron at each energy state within an atom or not more than two electrons at each energy level with opposite directions of their magnetic or mechanical moments (spins). Electrons in an atom occupy the lowest possible energy levels. The number of electrons in each shell cannot exceed twice the number of energy levels of the shell, which is equal to $2n^2$, where n is

the number of the shell or the principal quantum number, which can have the values 1, 2, 3, 4 ... and so on.

When a solid body is formed from individual atoms, the state of the electrons moving round nuclei in internal electron shells remains practically unchanged. The external or valence shells interact vigorously when atoms approach one another, split and combine, forming a valence band of allowed energies of the solid body. In a number of solid bodies this band is followed by a band of forbidden energies and then a band of possible energies in which at a temperature of absolute zero there are no electrons.

The number of levels in the valence band is equal to the number of levels in the corresponding shell of each atom multiplied by the number of atoms in the solid body. The width of the valence band does not depend on the dimensions of a crystal but is proportional to the cube root of the atomic concentration. For different crystals it has a value of the order of 5–10 eV. If a crystal contains 10^{23} atoms per cubic centimetre, the distance between adjoining levels in the band comes to 10^{-22} eV. This is an infinitesimal energy, even when compared with the average energy of heat motion of atoms and molecules at room temperature, which is equal to 0.04 eV. If the valence band is completely filled with electrons, it is impossible to introduce even a single additional electron in any way. In this case, when the forbidden band is very wide, a solid body is a dielectric. Its electrons cannot be accelerated by any external electric field, i.e., they cannot acquire the additional energy corresponding to the conduction current. If the valence band is not completely filled, the solid body is a metal. Electric conduction is determined by the concentration and mobility of the charge carriers and depends on their number on the outer valence shell. The less the electrons' bonding energy with the nucleus, the easier they are detached from the atom and the easier they form deindividualized electrons. The above-mentioned metals have one peripheral electron, which easily leaves the atom. Iron, zinc and magnesium have two perip-

heral electrons and aluminium has three, and it is more difficult for them to leave the atom. Detachment of electrons from the stripped atom requires large expenditures of energy. Formation of a metal, semiconductor or dielectric when atoms are condensed to a solid body depends on the structure of the atoms and on the extent to which their valence electron shell is filled. In a solid body atoms are orderly arranged in space, forming a crystal lattice, which is formed by the lengthy repetition of a group of atoms termed the elementary cell.

Four types of crystal lattice are possible, depending on the character of the particles at the lattice points and on the character of the forces with which they interact with one another.

Metallic lattices. At the lattice points are arranged positive ions, between which deindividualized electrons split off from the atoms when the crystal was formed, move irregularly similar to the molecules of a gas. These electrons are current conductors and at the same time act as a cement holding together the positive ions of the lattice. The resistance of metals depends on the temperature. This is because at temperatures above zero, the ions at the lattice points are put into thermal harmonic vibration and the orderly movement of the electrons toward the outer electric field is disrupted, and the greater the amplitude of the vibrations, i.e., the higher the temperature, the greater this disruption. Consequently the resistance of metals increases as the temperature rises.

Atomic or homeopolar crystals. At the points of the crystal lattice there are like neutral atoms. This type of bond is found in graphite, diamond, silicon, germanium, etc. In this lattice the atoms are crowded so closely together that the electronic shells of their valence electrons are interwoven, thanks to which special exchange forces arise, causing greater cohesion. The nature of these forces is explained in quantum mechanics. By analogy with the hydrogen molecule, it can be considered that the homeopolar bond originates through the exchange of electrons moving in a common shell embracing both nuclei

of a molecule. Thus the homeopolar or hydrogen-like bond is effected by electron pairs and is directed in character.

Ionic or heteropolar crystals. At the lattice points positive and negative ions of equal size are alternately arranged, so that the crystal as a whole is neutral. The forces of interaction between the ions or the forces of the bond are the electrostatic forces of attraction between unlike charges (coulomb forces). The entire crystal can be regarded as a single giant molecule.

Molecular crystals. The lattice consists of molecules of water, oxygen, etc. The bonding force is determined by the force of attraction between the electric dipoles of the individual molecules.

3. ELECTRICAL RESISTANCE OF SOLUTIONS

Passage of electric current through a solution (the movement of electric charges) differs essentially from the movement of electric charges along a metallic conductor. The difference consists, above all, in the fact that in solutions the charge carriers are not electrons whose mass is only about $1/2000$ of the mass of a nucleon (proton or neutron), but the residues of atoms and molecules consisting at times of many large charged particles—ions.

Naturally this movement is accompanied, in one way or another, by a change in the properties of the substance itself. Let us consider an electric circuit in which one element is a vessel containing a solution of table salt in which two platinum electrodes of any shape are immersed. In the solution the current is the movement of heavy charged particles—ions. The appearance of ions signifies the possibility of chemical dissociation of the dissolved salt into its constituent elements, sodium and chlorine. Sodium, which loses an electron, becomes a positively charged ion moving toward the electrode connected to the negative pole of the power source for the electric circuit. Chlorine, which appropriates an electron, becomes a negative ion moving toward the electrode connected to the positive

pole of the power source. The formation of positive and negative ions takes place through the spontaneous break-up of the salt molecule in aqueous solution which is called electrolytic dissociation. Movement of ions is brought about by the voltage fed to the electrodes immersed in the solution. On reaching the electrodes, the ions take possession of an electron or give up an electron, thus forming molecules of sodium and chlorine, respectively. This process of chemical decomposition during the passage of an electric current (electrolysis) takes place in solutions of many other substances. The molecules of such substances, like the molecules of table salt, consist of oppositely charged ions, into which they dissociate in solution. The number of dissociated molecules, or to be more exact, the number of ions, characterizes the electrical resistance of the solution.

It should be reiterated that passage of an electric current through a circuit, one element of which is a solution, causes a transference of the substance forming this element of the circuit, and consequently a change in its chemical properties, whereas when an electric current passes over a metallic conductor no chemical changes take place in the metal. This is explained by the fact that in metal conductors the transfer of a certain amount of electricity takes place through the translation of free, or more precisely, deindividualized electrons; in solutions the transfer of this amount of electricity is carried out by ions having a great weight compared to electrons, and forming the basis of the substance in question. In the first case the passage of electricity is not accompanied by the transfer of the basic mass of the substance, while in the second case it is.

4. NEITHER CONDUCTOR NOR INSULATOR

1924 was the year in which wireless broadcasting began in the Soviet Union. The Comintern wireless station in Moscow, a giant in wireless engineering in those days, went on the air.

In Leningrad, too, programs were broadcasted regularly two or three hours a day. Thousands of fans of all occupations and ages enthusiastically set about making crystal sets. The detector in these receiving sets was a small silvery, semiconductor crystal, with which the loose end of a metal spring was in contact. The electric circuit included, besides the detector, a wire spiral (self-induction coil), a condenser and ear-phones or loud-speaker. Thanks to the properties of the semiconductor crystal, this apparatus "sensed" changes in radio waves and provided reception of the information carried.

But a diversity of other properties, equally amazing, are found in semiconductors, a large group of substances with a very broad range of conductivity—from 10^5 to 10^{-8} 1/ohm m.

In the most general sense these substances are something of a bridge between inanimate and animate nature. What is there in common? Many semiconductors, like living organisms, are highly sensitive to environmental effects and react to them with changes in their electrophysical properties. The relationships in these changes are of course different, but there is undoubtedly something in common. Thus, the conductivity of semiconductors, inorganic and organic, increases sharply as the temperature rises, while in metals it falls. In some semiconductors, conductivity depends on the intensity of illumination, while in others voltage appears under the influence of light. Such semiconductors find application as sources of electric energy, and are used for making solar batteries. Semiconductors in which electric current appears under the influence of penetrating radiation (including X-rays) are also used as sources of electric energy. The electric properties of semiconductors can change under the action of pressure, humidity, chemical composition of the air and other environmental factors.

Man can assess changes in environmental conditions through changes in the bioelectric potentials of the visual, acoustic, gustatory and tactile analyzers. Analogy, no matter how tempting it may be, is not proof, but evidence of the similarity of

inanimate and animate nature is gradually accumulating, and it can be assumed that this will continue. But more of that later.

Semiconductors are widely employed in various sectors of the national economy as transducers of environmental characteristics into registered electric signals. The strength of the electric signal is proportional to the change in the primary characteristic.

The conduction properties of semiconductors are explained by the band theory of solids. For an electron to jump from the valence band to the conduction band it must be given additional energy, since an electron cannot possess an energy lying within the range of the energy values of the forbidden band. An electron can be given the energy for its jump from the valence band to the conduction band by heating or by the action of an electric field, penetrating radiation or light, i.e., by the action of any external source of energy. The following is characteristic of semiconductors, a category which includes a great number of diverse materials: when an electric field is applied to a semiconductor crystal and an electron jumps from the valence band to the conduction band, a vacancy—a “hole”—is formed in the valence band. In the absence of an electric field, the hole moves irregularly about the crystal, but under the action of a field, it moves in that direction. In an ideal semiconductor crystal, free from defects or impurities, the valence band is completely filled with electrons at absolute zero (0 Kelvin, -273°C), while the conduction band is empty, and the semiconductor becomes an insulator. At that temperature metals possess conductivity.

Parallel with the generation of electron-hole pairs in a semiconductor under the action of heat, there is a recombination of electrons and holes. When conduction electrons encounter holes in the valence band they fill them. The simultaneous action of these processes leads to the establishment of an equilibrium in the semiconductor, characterizing the equilibrium concentration of charge carriers. At room temperature

this concentration is many times smaller than the concentration of valence electrons. For example, in germanium, a typical semiconductor, there is only one conduction electron to ten thousand million valence electrons at room temperature. Still even this small number of charge carriers is sufficient for the semiconductor to possess perceptible conduction. This is explained by the fact that conduction depends not only on the number of charge carriers, but also on their mobility. In pure semiconductors the mobility of the electrons (charge carriers) is much greater than in metals. This mobility and the fact that the concentration of electrons and holes can change at room temperature explain the high sensitivity of semiconductors seen in variations in their electrophysical characteristics, depending on environmental factors.

5. SEMICONDUCTORS WITH IMPURITY CONDUCTION

Besides semiconductors with intrinsic conduction there are semiconductors with impurity conduction, in which some of the atoms of the initial substance are replaced by atoms of other elements whose energy levels are in the forbidden band. Impurity atoms are of two types—donors and acceptors. Donors when introduced into the crystal lattice give up an electron to the conduction band. Acceptors, on the contrary, can seize an electron from the valence band, thus forming a hole. The difference between semiconductors with intrinsic conduction and those with impurity conduction lies only in the degree to which impurities influence their conduction. If the concentration of donors in the semiconductor exceeds the concentration of intrinsic conduction electrons, it is the conduction electrons that make the greatest contribution to conductivity, since their concentration, n , will be much greater than the concentration of the holes, p . Such a semiconductor is called an electronic or n -type semiconductor to distinguish

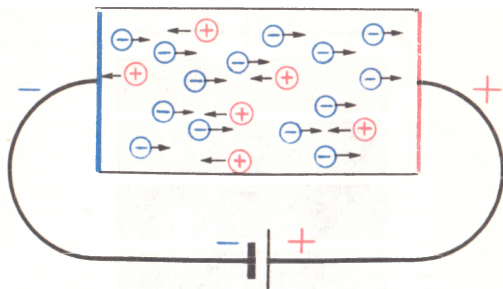


Fig. 1. Movement of charge carriers in *n*-type semiconductor

it from a hole or *p*-type semiconductor, in which the number of holes is greater than the number of electrons.

Semiconductors with impurity conduction have different properties than chemically pure semiconductors. Consequently the presence of impurities in semiconductors greatly extends their application. What impurities are there? Impurity atoms can be trivalent or pentavalent, while the most popular semiconductors, germanium and silicon, are tetravalent.

Thanks to the presence of pentavalent atoms in a medium of tetravalent atoms (Fig. 1), free electrons appear in the semiconductor from each pentavalent atom of the impurity (indicated in the Figure by minus signs). As a result, the pentavalent atoms become positive ions, indicated by plus signs. If electrodes are attached to a piece of germanium and a potential applied, there will be a current in the circuit exceeding the current from intrinsic conduction. The free electrons, superfluous in a system of tetravalent atoms in the presence of pentavalent atoms, will begin to move toward the positive pole of the potential source. Such impurities are donors since they give up electrons. In the semiconductors used in practice there is one atom of impurity to $10^8 - 10^4$ atoms of germanium. By using such a ratio of impurity atoms to basic atoms it is possible

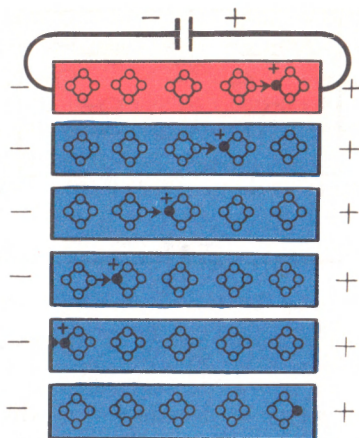


Fig. 2. Movement of charge carriers in *p*-type semiconductor

to obtain a semiconductor with preset properties and characteristics.

But what will happen if the impurity atom has three electrons in its valence shell instead of five (Fig. 2)? The trivalent atom has chemical affinity with three neighbouring basic tetravalent atoms, a void or hole being formed in the fourth atom which can be filled by any electron. The system with three electrons has a tendency to attract an electron, and by detaching one from a neighbouring atom will make a hole in its valence band. Under the action of a potential the electrons will travel to the positive pole, and the holes, to the negative pole. Trivalent impurities are termed acceptors because in contrast to donors they accept electrons. Acceptor impurities include, among others, aluminium, thallium and indium.

This discussion of semiconductor properties would be incomplete if no mention were made of the phenomena observed

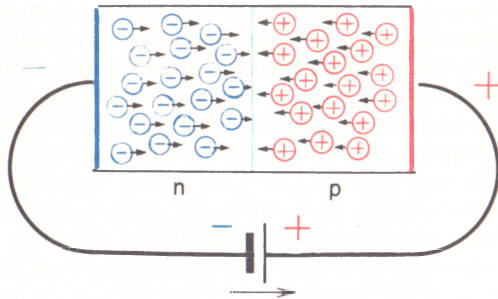


Fig. 3. Movement of charge carriers through p - n junction when the poles of the power source are connected to the sides of the compound semiconductor with the same signs of the charge carriers

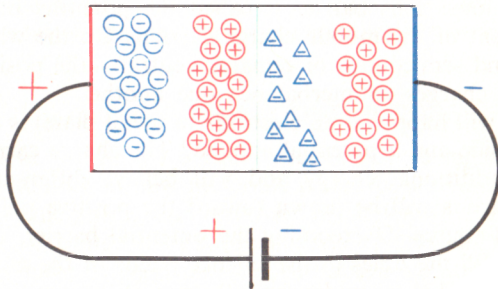


Fig. 4. Movement of charge carriers through p - n junction when the poles of the power source are connected to the sides of the compound semiconductor with the opposite signs of the charge carriers

when semiconductors with different impurities are joined (Figs. 3 and 4). The boundary of contact between two semiconductors with n and p types of conduction is called the p - n junction. Its thickness is measured in tenths of a micron. This extremely thin layer imparts new and amazing properties to the compound semiconductor which are widely made use of in radio electronics. At the boundaries of both semiconductors the negative ions formed by the trivalent impurity atoms repel the free electrons coming from the semiconductor with a pentavalent impurity. In the region adjoining the contact boundary, all the acceptor atoms will be filled with electrons and converted into negative ions fixed at the lattice points. On the contrary, all the atoms of the donor impurity near the junction will lose an electron, thus making them positive. In the region of the junction, travel of the charge carriers—electrons and holes—will be made difficult. The contact boundary between the two semiconductors will be a sort of barrier between the two regions. One region will contain negative ions fixed at the lattice points; the other will contain positive ions. This barrier is called the potential barrier. It is deficient of the mobile charge carriers. On the whole, the compound semiconductor remains neutral—the positive and negative charges counterbalance one another.

What will happen if an electrode (a metal plate) is attached to each side and a potential applied? The charge carriers will receive additional energy and will behave differently. The free electrons will be drawn toward the positive pole of the potential source. Overcoming the potential barrier, they will begin to fill the holes in the valence bands of the atoms that have travelled there under the influence of the positive potential. The electrode connected to the positive pole of the source will attract electrons. A current will appear in the circuit. If the polarity of the potential applied to the electrodes is changed, the properties of the semiconductor will be different. The electrons of the electrode in contact with the negative pole of the potential source will draw a chain of holes from

the p section. In the n section of the semiconductor the electrode connected to the positive pole will attract the free electrons. These phenomena combined increase the potential barrier. If the same potential is applied, there will be no current. Until the breakdown voltage is reached, phenomena in the circuit characterized by the movement of charge carriers will only be due to the potential applied. When the applied potential reaches the breakdown value, the semiconductor will fail. Thus a compound semiconductor can be either a conductor, or an isolator depending on the polarity of the potential applied. For alternating current the semiconductor will be a rectifier.

There are many variations in the use of the peculiarity of movement of the charge carriers in this class of substances.

In view of the object of this book it is important to get an idea of the types and peculiarities of charge carriers, and their movement in materials known as semiconductors.

The conductivity of this class of materials, as characterized by the movement of the charge carriers, differs essentially from the electronic conductivity of metals, the ionic conductivity of solutions and the very slight conductivity of dielectrics.

6. ORGANIC SEMICONDUCTORS

The development of organic chemistry is bringing an increasing number of new materials whose basic characteristic, aside from the general carbon structure (skeleton), is the absence of free electrons. New organic materials possessing ultrahigh resistivity have brought about a veritable revolution in insulating technology—new insulation for wires and cables has appeared, microminiature radio-electronic parts are being manufactured and fundamentally new trends in the development of radio engineering are in evidence.

But coherent ideas of polymers as insulating materials began to break down as early as the end of the 'thirties. A very small number of organic compounds were found to possess

electrical conductivity properties of a kind. The first such compound was anthracene. When exposed to light, electrical conduction appeared, and this increased sharply as illumination was intensified.

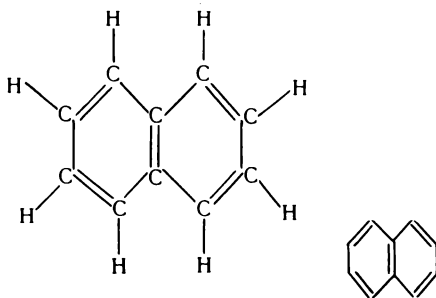
It is greatly to the credit of Academician A. F. Ioffe that he realized the significance of the phenomenon discovered, and immediately after the Great Patriotic War conducted extensive investigations into the semiconduction properties of organic compounds. However it was only in the mid-sixties that the immense potentialities of organic semiconductors began to be utilized. What are the common particularities of these materials? To begin with, there is the great range of conductivity values. For instance, some complex organic compounds, derivatives of tetracyanochinodimethane have a conductivity approaching that of metals. The activation energy, i.e., the energy required to set the charge carriers in motion, is very small. Beginning with potential values characterized by an electric field potential of 10^3 – 10^5 V/cm, the current/voltage relationship is close to Ohm's law. Besides the dependence of the conduction of some organic polymers on illumination mentioned above (photoconductivity), it has been found that conduction may be dependent on humidity, pressure, penetrating radiation and other factors.

The charge carriers, for example, for photocurrent, can be electrons or holes. Experiments carried out in vacuum, during which the layer of material was carefully sealed, showed that the sign of the charge carriers can change from positive (holes) to negative (directly acting electrons). This means that hole current is due to the presence of absorbed oxygen, a strong electron acceptor which alters the electron/hole ratio in favour of the latter. The effect of oxygen on the character of conduction is of great importance when considering electronic conductivity in living organisms, since the mechanism of energy transformation and transmission is apparently associated with this.

A. A. Dulov and A. A. Slavkin stress another characteristic

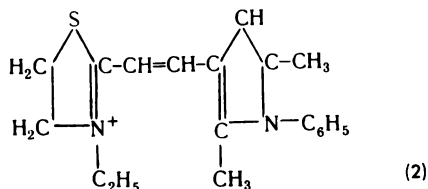
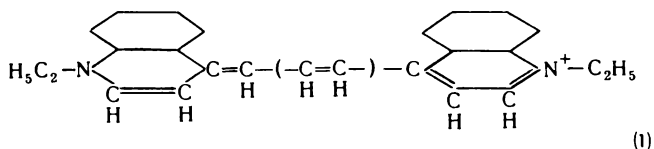
of organic semiconductors — the presence of magnetic properties.

Summarizing what has been said, it can be concluded that organic semiconductors essentially differ from most organic compounds. In the first place they have a large number of double (unsaturated) $C = C$ bonds forming a conjugated system, i.e., a system with a regular alternation of double and single bonds. A. A. Dulov and A. A. Slavkin cite naphthalene as an example. Large crystals of naphthalene can easily be obtained by slowly cooling a melt.



The skeleton of the conjugated system, as can be seen from the complete or simplified formula, is a chain of carbon atoms connected by alternating single and double bonds. Two electrons from two atoms are involved in the formation of the double bond, $C = C$. In the conjugated system the electrons interact within the entire molecule, forming a unified electronic system. In such systems the electrons are not bound with individual atoms or are bound very loosely. Consequently they are capable of moving about the entire molecule, thus bringing about bulk conductivity. As the number of electrons weakly bound to atoms increases, there is a corresponding rise in electrical conductivity. This has been confirmed experimentally and by quantum mechanical calculations. Thus, the greater the number of conjugated bonds, the greater the

conductivity. The energy holding the individual electrons in the molecule falls to 0.25 eV, and at times still lower. It is for that reason that the electrons easily become mobile charge carriers. But mobile charge carriers are not found in all compounds with conjugated bonds. For example, polymers described by formula (1) possess conductivity, but those described by formula (2) do not, in spite of the presence of conjugated bonds



If a slight energy of any form (electric field, light, heat, etc.) is applied to the semiconductor (formula 1), the conductivity will change. The type of conductivity can differ. It can be the usual electronic conductivity or the electron-hole-type conductivity, as in inorganic semiconductors.

The reader will recall the preceding section in which we spoke of molecules with an impurity of atoms of a different valence which imparted donor conduction (the atoms of the impurity gave up electrons to neighbouring atoms), or acceptor conduction (the atoms of the impurity detached electrons from neighbouring atoms). This is also true of organic semiconductors. In this case there is, in the structure of the substance itself, an alternation of molecules capable of giving up electrons (donors) and molecules capable of acquiring electrons (acceptors).

Conducting properties are also found in polymers, likening them to inorganic semiconductors such as germanium and silicon. They are also similar in a number of other characteristics. For instance, resistivity values, as a rule, are close. Both groups are characterized by the common shape of the curves for variations in conductivity under the action of heat, light, etc. But there are exceptions—because of the weak bond holding the electrons within the skeleton, some polymers have a conductivity close to that of metals.

The results of experimental studies of semiconductor polymers have been published in the literature. Organic semiconductors are now being used to an increasing extent in the most diverse fields of technology. Consequently no fewer investigations are being devoted to the development of processes for producing polymers. There is good reason for emphasizing the experimental character of the material published. Great difficulty is encountered in formulating a theory of the structure of such complicated substances, possessing, as they do, such a wide range of bond energy—from fractions of an electron volt to energies equal to the energies of ionization, i.e., possessing the conductivity of electrolytes in solution. Fundamentally new methods are required for tackling the study of the interdependent, interconnected condition of particles packed in a structure characteristic of a solid body and the liquid state. Development of processes for the production of organic semiconductors pursues the line of directed synthesis followed by chemical and thermochemical transformations in the chains of the macromolecule. Success has unquestionably been achieved in the application of both methods. Many new polymers of diverse properties have been obtained which possess conductivity varying over a wide range, and having a temperature dependence characteristic of ordinary semiconductors. The practical application of technological advances has revealed new properties found only in these substances. Recent publications give grounds for assuming that further studies in the physical chemistry and electronics

of organic substances with semiconductor properties in the macromolecule will promote still greater employment of new materials in electrical engineering, electronics and the chemical industry. There is probably no sector of the national economy in which organic semiconductors will not find application.

Scientists at the establishments of the USSR Academy of Sciences and at industrial research institutes are successfully developing their independent line in semiconductor investigations. Particular mention should be made of Academicians V. A. Kargin and A. V. Topchiev, and Doctors L. S. Stilban-son and B. A. Krentselin*.

Concluding this survey of organic semiconductors, the following should be noted. In the first place, concepts of the types of charge carriers found in nature have been greatly extended, and on the basis of these concepts it has become possible to formulate new hypotheses regarding the structure of matter.

Thus, study of inorganic and organic semiconductors has shown that in them the following types of charge carriers are found:

(a) Atoms, which on losing an electron in their outer shell become positively charged particles and participate in the transfer of positive charges;

(b) Electrons thus freed which become carriers of negative charges;

(c) Ionized acceptor atoms, i.e., atoms which have captured an electron from a neighbouring atom; they are also negatively charged particles and participate in the transfer of negative charges;

(d) Holes formed when valence electrons are captured from an atom; they begin to attract electrons from a neighbouring atom and become a sort of positive electricity carriers.

* *Organicheskiye poluprovodniki* (Organic Semiconductors), Edited by A. V. Topchiev, Moscow, 1963.

There are considerably more types of movement of the charge carriers in organic semiconductors. In them, translation is a combination of several complex phenomena, one of which is brought about by "vagabonding" electrons roaming about the molecule. Since the molecules differ, their bonds with electrons and molecules are most diverse.

An essential difference between metals and semiconductors and dielectrics of any kind is to be seen in the physical nature of the dependence of electrical conductivity in these substances on temperature. In metals, conductivity falls as the temperature rises; in other substances it rises. It would be well to return once more to a consideration of the phenomena characterizing the conductivity of metals.

In metals the charge carriers are deindividualized electrons which are very weakly bonded with the atomic nuclei, and possess wave properties. The electron moving in the metal can be considered a flat wave propagated in the same direction as the stream of electrons. Metals, having a crystalline structure, form a periodic lattice. A flat wave can pass through an ideal crystal without scattering. Consequently electrons or an electron stream can pass through an ideal crystal without loss of the energy they acquire if the metal is connected to a source of potential. The ideal periodicity of the metal's crystal lattice can be destroyed in two ways, thus causing resistance to the electron stream. At a temperature above absolute zero (-273°C) the atoms begin to vibrate relative to their equilibrium position. The vibrations increase as the temperature rises, and the electrons encounter mounting resistance (i.e., conductivity falls). Another cause of increasing resistance is the presence of impurities in the metal. It is extremely difficult to obtain metal free from impurities. The impurity atoms begin to move as the temperature rises, leading to the lowering of conductivity.

The simplified explanation can be illustrated by a still simpler analogy. Imagine a crowded square. The people are standing in a definite order, practically motionless, shifting from

one foot to the other, turning slightly round their original or equilibrium position. Next imagine some athletes, runners, come up to the square, which they must cross. So long as the crowd remain standing in order, the athletes have no trouble in crossing the square, winding in and out among the people. But if the people become excited or disturbed for some reason and start moving about, the runners will find it very difficult to push their way through to the other side. They must expend much energy overcoming the resistance they meet.

In nonmetals, phenomena are different. Here there are no deindividualized electrons. The energy of the bond between electron and nucleus is much greater. It is true there are some nonmetals in which the bonding energy is small, but nevertheless it is greater than in metals. On heating such substances, the atoms begin to vibrate, and this may disrupt the electron-nucleus bond, but this only occurs when the vibratory energy is very great. Breaking the electron-nucleus bond causes the formation of free-moving electrons and the appearance of electrical conduction, which increases as the temperature rises.

And now what becomes of our analogy if it is altered to illustrate the behaviour of nonmetals. Let us imagine the same square crowded with the same number of people, but in this case they are all holding hands for a round dance or some ring game. It is impossible or extremely difficult for the runners to cross the square. Then the people begin running very fast (similar to the greater mobility of electrons as the temperature rises) and the rings and chains break, making it easy for the athletes to run through the crowd.

This analogy should make it easier to understand the similarity and fundamental difference between the electrical conductivity of metals and nonmetals.

CHAPTER TWO

Electrophysics of the Living Organism

1. AMAZING ELECTRICAL CONDUCTIVITY

For a long time chemistry was divided into inorganic and organic, and it seemed that it always would be.

Advances in physics developed and consolidated the materialistic conception of the world as eternally existing matter. Materialistic views also triumphed in chemistry. In 1828 Wöhler synthesized urea, an animal product, from inorganic material, and the theory of the "vital force" was dealt a serious blow. A merging of inorganic and organic chemistry began. The concept of chemistry as a single science has now become dominant.

Organic chemistry and biochemistry are nothing but more complicated fields of inorganic chemistry. By employing the latest techniques of inorganic chemistry, it is possible to solve problems involving compounds of nitrogen and carbon, the basic substances of the living organism. The possibility of creating the animate from the inanimate is becoming a reality.

The teaching of the animate and the processes taking part in it is characterized by internal unity which assumes the existence of biophysical-chemical evolution which gave rise to biological evolution, thus bringing about all the diverse forms of modern plants and animals, and man himself. This principle, formulated by the outstanding materialist-physicist, John Bernal, is being developed in biophysics and biochemistry. The ideas of John Bernal and other like-minded scientists

predominated at the Fifth International Biochemical Congress held in Moscow in 1961.

A deep-going study of the electrophysical properties of living tissue is of great theoretical importance. It is a fact that when a living organism of any species comes into being, bio-electric phenomena set in, which only weaken and cease with the death of the organism. B. N. Tarussov, and not only he, consider electrical conductivity an inherent characteristic of vital activity. This theory finds application in the well-known electrodiagnosis of the activity of the heart muscle registered in the electrocardiogram. It is absent in the dead. In the dying, the curve changes in shape, amplitude and the intervals between the individual cycles.

The electric properties of the living organism were first noted and studied in the middle of the 19th century. In the 80's of the 19th century, I. P. Tishkov carried out the first investigations of electrical conductivity in the body of living man. In his work *O soprotivlenii chelovecheskogo tela elektricheskomu toku* (Resistance of the Human Body to Electric Current) published in 1886, he cited numerical values of resistance without disclosing underlying principles. Wilhelm Weber, a German physicist, who conducted similar investigations, attempted to prove that in its electrophysical characteristics, the human body or the body of any living organism could be likened to salt solutions or ordinary electrolytes. In spite of the fact that those investigations were carried out a very long time ago, the assertion that in its electrophysical characteristics the body of the living organism is a salt solution is voiced to this day, although there is ample evidence, experimental and theoretical, proving that this view is erroneous. In this connection it would be well to consider, if only briefly, the semiconductor properties of living tissue.

On the very eve of World War II Albert Szent-Györgyi, the eminent Hungarian biochemist, spoke of the importance of studying the "electronic properties" of living tissues to increase our knowledge of the living organism. It was his view that

a number of very complicated phenomena could be explained by the transfer or movement of electrons in the macromolecule or group of molecules of the living organism. On Albert Szent-Györgyi's 70th anniversary a collection of articles by leading scientists in different fields was published under the title "Horizons in Biochemistry", (Academic Press, New York-London, 1962). The articles devote considerable attention to the results of investigations into the electrophysical phenomena in the living organism — biotissues and biofluids. The articles by L. Brillouin, D. Eley and J. Duchesne were of particular interest, since their approach to biochemistry was from the positions of modern theoretical physics. Szent-Györgyi's brilliant idea of comparing the properties of the gigantic biological molecules with the properties of semiconductors aroused immense interest. Life is a continuous process of the absorption, transformation and transfer of energy of different types and values. We must find the mechanism explaining the movement (transference) of energy along the molecules of the living body. One mechanism which can explain many processes taking place in the living organism is provided by the electronic theory of semiconductors developed in solid-state physics. The macromolecule of the living organism is in many ways equivalent to the semiconductor molecule, although the phenomena taking place in it are much more complicated.

A number of experiments have been carried out at Soviet and foreign research establishments which show that our knowledge of phenomena characteristic of organic semiconductors can be extended to biological objects. The substances studied were diverse types of protein compounds, including various enzymes, and a number of other vitally important substances of the organism. Researchers were unanimous in their opinion: the transfer of electrons, their polarization, the formation of new charge carriers, and their interrelation with electrons—that was the line of investigations which could reveal many secrets to mankind.

This line is not at odds with the basic principles of modern biology formulated by S.E. Bresler*. According to Bresler the principal carriers of chemical energy in living organisms are the macroergs of 16 species of nucleoside triphosphate. Their structure is characterized by a chain of three anhydride-bonded molecules of phosphoric acid. The bond between the phosphates is termed macroergic because the hydrolysis of phosphate compounds takes place with a great lowering of the free energy. For that reason these compounds readily give up their phosphate to other molecules. A more detailed deciphering of this principle will undoubtedly be associated, directly or indirectly, with the deciphering of the movement and migration of charge carriers.

What the study of biological objects from the positions of semiconductor theory has already contributed should be noted. Firstly, elements and even whole molecules have been found which act as donors and give up electrons, and also acceptors which detach electrons from their neighbours. Secondly, a fundamentally new particularity of the electrophysical properties of biological objects which is not observed in either inorganic or organic semiconductors has been established—the presence of extremely small bonding energy. For the ordinary ionization of a solution or a solid an energy of the order of 20-30 eV is required. For the majority of the giant biological molecules the energy required is only a few electron volts, or even a fraction of an electron volt. Such data have been obtained for the most diverse biological objects. It has been assumed that the charge carriers are electrons which move about through what is known in semiconductor science as the tunnel effect. Thanks to this effect the electrons move from one molecule into another.

Experimental techniques for studying the electrophysical properties of biological objects have been substantially improv-

* Bresler, S. E., *Vvedeniye v molekulyarnuyu biologiyu* (Introduction to Molecular Biology), Moscow and Leningrad, 1966.

ed. Installations and apparatus are now in use making it possible to determine the electrophysical characteristics of these objects when absolutely dry and under a high vacuum. It has thus been possible to determine the electrical conductivity of most proteins over different temperature ranges. In many types of proteins and protein substances polarization is small. This means that conductivity is brought about by electron-hole-type carriers, since the temperature dependence of conductivity in the absence of impurities is linear. A number of aminoacids of great importance in the organism's vital activity have similar conductivity values with varying dependence on environmental factors (see Chapter One, Par. 5).

Another particularity of the electrophysical properties of protein and other biological substances is the great mobility of the charge carriers. This is shown by application of the theory of the potential barrier (Chapter One, Par. 4) to protein compounds. Apparently the carbon-oxygen and hydrogen-nitrogen bonds are of major importance. In such a system of hydrogen bonds the excited electron can penetrate the potential barrier through the tunnel effect and consequently migrate through the entire protein molecule. This leads to a substantial overall displacement of the electron, thus bringing about its mobility and making the protein molecule highly conductive. A number of studies have shown that the presence of water increases the dielectric constant of the protein system, which facilitates the formation and separation of ions. It has been demonstrated that in this case protons are the predominant charge carriers.

Summing up the particularities of the electrophysical properties of biological substances, it can be asserted that the charge carriers in proteins and other elements of the living organism are ions (protons and electrons), which in combination with the system of electron-hole conduction create a single conductivity, characteristic only of the living organism. When the water content is increased, the charge car-

riers can be predominantly protons. In dehydrated biological substances they are apparently electrons. But as yet, the results of many investigations are contradictory. A number of authors, for example, have found that chloranil acts as an acceptor when a small amount is added to a protein and increases conductivity a million times. The addition of water, on the other hand, lowers conductivity to one-tenth of the initial value. Water acts as an electron donor and apparently at first fills the positive holes, lowering conductivity 10^6 times. Electrons are then given to the proteins, and the conductivity increases 10^5 times, the net result being a lowering of conductivity 10 times, i.e., to $1/10$ of the initial value.

Other substances, such as nucleic acids and nucleoproteins play as important a role in the body as proteins. Structurally, they differ from proteins since they have hydrogen bonds involving other elements, but they are similar to such nonbiological substances as graphite. They are characterized by the general electrophysical properties of protein compounds. Thus, the bonding energy ranges from 1.0 to 2.5 eV. Specific conductivity is high but several orders lower than that of proteins. The mobility of the charge carriers is also somewhat lower. But on the whole, their electrophysical properties and the phenomena causing them have the same general relationships as the analogous properties of proteins. Nucleic acids possess properties characteristic only of them (among biological substances).

The French researchers, J. Duchesne and A. Monfils developed and employed a method for determining weak piezoelectric properties in diverse materials. The method consisted essentially in placing the test substance in the alternating field of a capacitor connected to a highly sensitive radiometric system which provided important information about the electric, thermal and mechanical properties of the substance or complex compound placed in the capacitor field. When this method was applied to nucleic acids it was found that they possessed piezoelectric and thermoelectric properties,

and that these properties depended to a great degree on the presence of water. By changing the amount of water it was possible to alter the piezoelectric properties. Study of electrical conductivity phenomena with this technique again confirmed that these substances possess a particular form of conductivity, which has not, as yet, been precisely characterized.

Let us attempt to sum up the facts set forth in this section. Quite a number of the compounds studied, substances of the greatest importance for the vital activity of man, animals and plants, possess semiconductor properties in the crystalline and amorphous states. Semiconductor properties are also characteristic of organized biological systems. For example, the rods of the retina have photoconductor properties. At the same time the molecules of living organisms possess electronic conductivity, similar to the conductivity of some polymers.

The growing number of studies of the electrophysical properties of biological systems and organisms as a whole reveal new and particular electrophysical phenomena, characteristic only of the living organism. A mutual enrichment of biology and the technical sciences is taking place—this is particularly true of electrical engineering.

Actually, electrical engineering can embark on a new stage of development if it proves possible to produce systems similar to proteins and nucleic acids, possessing weak electronic bonds, high conductivity, semiconductor properties and special sensitivity characterized by a change in the electric signal, depending on pressure and temperature.

Conversely, the possibility of investigating the electrophysical properties of biological systems by the methods of study of modern theoretical and experimental physics, particularly electronics, will open a new stage in the development of biology and the acquisition of knowledge of man's body and its ills.

2. SIGNIFICANCE OF CHANGES IN THE ELECTRICAL PROPERTIES OF THE LIVING ORGANISM

Reanimation, the science of saving a person who has all but lost signs of life, has achieved a great deal. Its methods are being employed to an ever greater extent in emergency practice in ambulances and at hospitals and clinics. When saving life, the electrical activity of the heart is sometimes recorded. I. V. Shaban, a reanimation enthusiast, has made the following observation. Life is waning but the curve showing the electrical activity of the heart, the electrocardiogram, retains its shape. As long as the electrical activity of the heart is maintained, the fight to save the life of the dying patient continues and in many cases the patient is saved.

What then happens when death occurs? Changes appear in the electrocardiogram. These changes quickly increase and then electrical activity ceases. Sometimes individual disorderly electric impulses are observed for an hour. The man is dead. What has happened? The number of atoms and molecules, i.e., the amount of matter comprising the body, alive or dead, if it could be determined before and after death, would be found to be practically the same. From what has been said, we single out this: what has changed is the movement of the charge carriers — the electrons and ions. Perhaps that is one of the keys to the mystery of death, and future researchers with more advanced techniques at their disposal will establish the underlying principles of the movement of electrons, ions and other charge carriers in the living organism, and its direct relation to vital activity. Perhaps one of the principal differences between the animate and the inanimate lies in different atomic, molecular and intermolecular electronic bonds in the structure of the living and even in structurally related synthetic organic substances. The distinction may be in the different migration of the electrons from molecule to molecule, in the peculiar movement of the ions, resulting in a particular type

of conductivity and a particular type of polarization characterized by an accumulation of charge carriers, as recorded in the electrocardiogram, etc. Perhaps Szent-Györgyi was prophetic when he wrote: "I am firmly convinced we shall never understand the essence of life if we limit ourselves to the molecular level. After all, the atom is a system of electrons stabilized by a nucleus, while molecules are nothing but atoms held together by shared electrons, that is, electronic bonds."*

Developing this thought, it can be assumed that the molecules of the animate are molecules interconnected by the energetics of the motion of charge carriers, the migration of electrons possessing a particular conductivity inherent only in the animate. Even the usual, well studied types of conduction like the ionic, electronic and electron-hole types have specific features in the animate. There are also specific features in the combined mobility of the charge carriers and in the value of conduction, polarization and in much else. But this is not simply a sum of all types of conduction: $1 + 1 + 1 = 3$. While centring attention on the movement of charge carriers it must be distinctly remembered that interaction of the electromagnetic fields takes place simultaneously and in association with it. There is an interconnected orientation of the magnetic moments of the elementary particles, and simultaneously, continuously and discretely the molecules and their constituent atoms jump from one energy state to another. The constantly changing excited state has a specific effect on the mobility and motion of the living organism's electrons and ions. This applies, above all, to the central nervous system. Only this complicated superimposing and combining of bioelectrophysical properties can explain the organism's responses to a number of environmental factors. An example makes this clear: 10^{-7} milligram of botulotoxin can be fatal.

*Szent-Györgyi A., "Bioelectronics. A Study in Cellular Regulations, Defence, and Cancer", Academic Press, New York-London, 1968.

Thus, combined conductivity is something of a starting point for unravelling the mystery of the animate. A new and important approach in this work is combining the study of the energy jump of the unexcited molecule and atom to the excited state and vice versa, with the simultaneous study of the formation and migration of charge carriers. That the excited state of the molecules is characteristic of the living organism is evidenced by the luminescence of some insects and microorganisms. Here it is manifested in a macroeffect but it is absolutely true to suppose that it also takes place within the organism. This goes to show the importance and complexity of the organism's bioenergetics. It would seem that study of electrical conductivity of the animate should facilitate gaining knowledge of bioenergetics at any level—from any species of organism down to the cellular and molecular. It would be useful to draw on the biophysical methods of overlapping sciences for studying the effect on the living organism of electromagnetic radiation over any range. The author's original hypothesis of the primary action of penetrating radiation holds out promise. The author suggests that the action is first manifested in atoms of metal, e.g., iron, present in the tissues. Experiments show that there is a change in the valence of these atoms and that there is a selective action of radiation of diverse wave length. Continuing the logic of the author's reasoning it can be assumed that there will be a change in the mobility of the charge carriers. It would not seem fantastic to believe that if the most sensitive instruments were available for measuring combined conductivity it would be possible to assess pathology of one kind or another and thus approach knowledge of the essence of the animate. If one assumes that scientists succeed in establishing the fundamental relationships governing the movement of charge carriers and electrons in the living organism, and construct a model of this movement, the model would not be a living organism. There are still many natural phenomena which are hidden from us. But this by no means detracts from the importance of the aforesaid.

Of course what must be done first of all is convincingly to demonstrate the presence of electronic and electron-hole conductivity in biological objects and describe the specific features of their conductivity as a whole. This is no easy matter but feasible if the advances in modern theoretical physics are made use of. It should be added that the hypothesis that it is the specific characteristics of the movement of charge carriers in the animate that distinguish the animate from the inanimate—a hypothesis formulated by Szent-Györgyi and developed by his pupils in various fields—already appears to be well-grounded.

3. EXAMPLES AND EVIDENCE

The extremely delicate mechanism of cellular regulation and the energy transformations manifested in the speed of reaction of the organism as a whole and the individual analyzers to environmental changes and external stimuli and the speed of processing this information assessed by the value of electrical activity can be explained by these processes being based on the movement of charge carriers. The extremely complicated metabolic processes in the cell and the transformation of diverse forms of energy in the cell or its elements, such as the mitochondria*, can only be explained by energy being transferred by particles having a mass less than that of an atom, and in the first place, directly and indirectly, by electrons.

Electrical activity of the brain is assessed by its potential pulses (waves) of diverse frequency. This is the result of the study of hundreds of thousands of sick and healthy people and hundreds of thousands of test animals. It has been established that in man the following rhythms are the most pronounced:

- (1) Delta-rhythm—from 0.5 to 3 waves per second;

* Mitochondrion—a structural element of the cell associated with energy transformations.

- (2) Teta-rhythm — from 4 to 7 waves per second;
 - (3) Alpha-rhythm — from 8 to 13 waves per second;
 - (4) Beta-rhythm — from 14 to 35 waves per second;
 - (5) Gamma-rhythm — from 35 to 55 waves per second.
- Greater frequencies are sometimes recorded.

In amplitude, the waves range up to 500 microvolts. It is impossible to obtain pulses of such frequency and amplitude from charge carriers of the ionic type alone. Electrochemical sources of current are inertial. Such temporal changes in electrical quantities, even if amplitudes are small, cannot be obtained directly with ionic conductivity. This can be considered direct evidence of the presence of electronic movement of the charge carriers in the brain and nervous system as a whole.

Let us consider a reanimation experiment with a dog. An experimenter is studying conditioned reflexes in a dog. During the experiment the dog accidentally receives a mechanical head injury. The dog stops breathing and its heart stops beating, which is shown by the electrocardiogram being recorded in the experiment. It would seem the dog is dead. A source of pulse potential is connected to the electrocardiograph electrodes already in place on the animal's body. The potential fed to the dog comes to several kilovolts, which is delivered for some hundredths of a second. At times it is only necessary to feed voltage once and life returns to the "dead organism". It is important not to lose time. The dog in the experiment described was reanimated. If delivery of pulse potential can be carried out within 8 to 10 minutes, the wonder of reanimation becomes a reality. Life can also be restored in cases of death from electric shock. The instrument employed in such reanimation procedures is called a defibrillator. It is not necessary to go into the design of this instrument—it is not complicated, and is used with increasing frequency in clinical practice during operations in which the patient suddenly loses all signs of life. V. N. Negovsky, Member of the Academy of Sciences, has been awarded the State Prize for developing, in collaboration with other researchers, a method of defibrillation and

introducing it into medical practice. A team of scientists headed by V. N. Negovsky has carried out a vast number of experiments of great diversity on test animals and achieved remarkable results.

There is every ground for explaining reanimation in this way. As a consequence of the most diverse causes, migration of electrons is disturbed in the cells of the central nervous system responsible for regulating cardiac activity. Disturbance of the established migration of electrons leads to disturbance of the self-regulating bioenergetic system of the living organism; metabolic processes cease and all the symptoms of death set in. Applying to the organism in the first stage of impairment—deregulation—an external electric field with a surge of charge carriers, restores the movement of charge carriers inherent in the living.

N. L. Gurvich*, one of the authors of this method, rightly associates the effectiveness of defibrillation with the shape of the curve of the pulse potential delivered. This is evidence that in defibrillation there is a regulation, a restoration of the movement of charge carriers characteristic of the living organism—a restoration of the former conductivity.

The authors of the defibrillation method of restoring the heart beat assume that when electrodes are placed on a person's body in the thoracic region, the current pulses will act directly on the heart muscle. While not denying this possibility, it must be pointed out that the pulses will simultaneously act on the heart through the central nervous system by which current reaches the vital regulatory centres of the nervous system. The nervous system's conductivity is much greater than that of the muscular tissue and the circulatory system; it interacts with everything associated with vital activity, greatly surpassing other systems in the speed of reaction to any impulse, particularly an electric impulse. What is dominant in

* Gurvich, N. L., *Fibrillyatsiya i defibrillyatsiya serdtsa* (Fibrillation and Defibrillation of the Heart), Moscow, 1957.

restoring the normal sequence of heart contractions? There are grounds for assuming that it is restoration of the specific movement of the charge carriers characteristic of the animate.

Let us go on to the next example. It was observed long ago that sudden impulses caused a sharp change in the body's electrical resistance. The experiment is extremely simple, and is carried out as follows. Electrodes like those already mentioned are placed on a person's body, but this time they are not connected to an instrument for recording electrical activity but to an instrument called a resistance bridge, used in this case for measuring the body's electrical resistance. Without warning, a bright light is flashed in the examinee's face, or a bell is sounded, or he is touched with a hot object or told an astounding piece of news. In all cases, no matter what the nature of the impulse—visual, acoustic, thermal or more complicated, mental—the electrical resistance falls. The resistance falls quickly from a sharp stimulus. The resistance is restored much more slowly, and this also depends on the nature of the stimulus. If the body had only the usual ionic conductivity, i.e., conductivity associated with the transfer of matter, changes in electrical resistance would proceed much more slowly. The rapid change in electrical resistance under the influence of stimulating factors can be explained by the presence in the “aggregate” resistance of the human body, a resistance associated with some form of electronic conduction. This is also indirect evidence but sufficiently convincing.

And now one more example, the last. A fatal accident in which a person lost his life by coming into contact with a live wire was described over a hundred years ago—in 1862 to be exact. Death was instantaneous. This was the first case of death from electric shock on record. But as the use of electricity increased, such accidents became more frequent. Opinion was unanimous that death was instantaneous and that there were no bodily changes to be seen. The only exception was when there were burns from an electric arc.

At the end of the 19th century experiments were begun on ani-

mals to determine the threshold, or dangerous, values of voltage and current. The determination of these values was necessary for working out protective measures. At the beginning of the 20th century contradictions arose regarding both the dangerous values of electricity and the mechanism of shock, especially when information began to appear about the agonizing and not instantaneous death of convicts executed in the electric chair. Without going into these contradictions, it should be noted that at times people are killed by electric shock when both voltage and current strength are very low, and survive when the potential is several kilovolts and the current strength, hundreds of milliamperes. The Austrian physicist, Jellinek, founder of the science of the danger of electricity, who was struck by this fact when investigating electric shock, suggested back in the late 'twenties that in many cases of electric shock the "attention factor" is decisive, i.e., the outcome of shock depends to a great extent on the state of the nervous system at that moment. This will be discussed in greater detail in Chapter Five.

What is important for the present is that when death occurs instantly from electric shock there is apparently disruption of the electrical conductivity of the central nervous system, which controls the basic, vitally necessary functions of the body.

Opinions differ to this day. Some scientists, basing their views for the most part on experiments on animals, assert that for a person to be killed by electricity a fairly large current strength is required, at least several score milliamperes. Other scientists who have investigated cases of death from electric shock in men claim that weak currents, up to 10 milliamperes, can be fatal, and even suggest that such cases are the most typical. This can only be explained by disruption of the movement of the charge carriers in the cells of the brain, which can take place in a number of circumstances, including very small potentials and very weak currents from external sources of potential; this disruption causes complete or partial stoppage of oxygen delivery to the cells.

It was demonstrated above that in complex polymers, especially in biological polymeric systems, the energy of the bond between electrons and the nucleus is very small—at times in the 0.01 eV range or even smaller. When a current of one microampere passes through a person's body during electric shock, the energy absorbed in the tissues is many orders greater than the bonding energy of the nervous system's electronic structure, and consequently there is every ground for assuming that even very weak currents can disrupt electrical conductivity and cause very serious disorders of bodily functions. Why this takes place will be discussed later. Meanwhile this example can serve as evidence of the specific nature of electrical conductivity in the living organism, and the unquestionable presence of electronic and electron-hole conductivity.

It is not only electric shock that can cause sudden death without visible external or internal injury. Suffice it to mention that micrograms of some poisons cause instantaneous death, and as yet nothing can be done to save the victim. In this case, too, there are undoubtedly sharp changes in the body's electrophysical characteristics, particularly in the central nervous system.

Here, too, an analogy should be useful. The life of a town depends on the electric power supply. There must be electricity for lighting, for the radio and TV set, for refrigerators and the scores of household appliances. Suddenly there is a power failure from a short circuit or overloading—the lights go out and everything comes to a standstill. As everyone knows electricity is supplied over cables or wires—metal conductors in which electrons are moving. If there is a break in the line or a fuse burns out or a switch is pulled, movement of the electrons stops.

Many things can happen. Say repairs are under way in an apartment. A falling chunk of plaster breaks the wiring or the wiring is damaged when moving a heavy piece of furniture.

If there is a fire, the insulation on the wiring will be destroyed, causing a short circuit and blowing a fuse or setting off the

automatic circuit breaker. Whatever the cause, breaking the circuit stops the movement of the electron charge carriers, i.e., stops the supply of electricity to the consumer. This analogy illustrates the interconnection of changes in the movement of the charged elementary particles and changes in phenomena of the macroworld.

The disruption of combined conductivity, polarization and electrical activity in the living body can ensue from many causes, and often results in death or serious consequences.

It would seem that the results of investigations along this line already carried out or to be carried out later should make it possible to explain a number of diseases of the central nervous system as being due to disruption of electrical conduction and electrical activity in the living body. Investigations should be comprehensive with the direct participation of specialists in different fields, including clinicians, experts in diseases of the nervous system, which are noted for their complexity.

A deep-going and comprehensive study of electrical conductivity cannot be an end in itself. The intramolecular and intracellular movement of charge carriers is associated with the energetic mechanism of conveying oxygen and other environmental components to the cell. Transformations of all forms of energy in the living organism make life possible, are the basis of life. Consequently, study of the mechanism of the electrical conductivity of living tissue is one of the ways of gaining knowledge of the animate. If it becomes possible, as undoubtedly will be the case, externally to influence and control electrical conductivity in the cell and in the living organism as a whole, inexhaustible means will appear for controlling the diseases of man and prolonging his life.

Much that is new awaits researchers studying electrical conductivity in the animate. There are grounds for assuming that conductivity in living organisms varies. Apparently electronic and electron-hole conductivity is found in the structurally more complicated and functionally more important systems. The researcher studying the ionic component of conductivity

will also discover much that is new. Of course, the transfer of matter by ions that have lost electrons and are incapable of retaining them may also differ in the living organism from ionic conductivity in the inanimate.

Modern electronics also takes in the study of the specific features of electrical conductivity in the animate. Its future lies in the study of microelectronic elements, the phenomena involved being employed at the atomic and molecular level. Research in the field of control with small quantities of energy as found in the living organism holds out great prospects for new solutions of engineering problems which will find application in control systems, in producing materials with new physical properties, etc.

Modern microelectronics and microradio-engineering with their film and integrating elements is far removed from wire and tube radio engineering of yesterday. But as yet there is still an immense distance to cover between modern microelectronics—a new stage in technical progress—and the biomicroelectronics of the living organism. Knowledge of biomicroelectronics and its application in the national economy will mark a new stage in the technical revolution.

Our knowledge of bioelectrical phenomena, however, even nowadays is of great aid in diagnosis and treatment of practically any disease.

CHAPTER THREE

Physical Properties of the Biosphere

1. ELECTRICITY ROUND US

Many years have passed since the death of Georg Rikhhmann, so vividly described by M. V. Lomonosov. The physicist was learning how to control electricity. At all events lightning rarely destroys buildings now. But people are still struck by lightning, which one calls to mind during thunderstorms. During storms people sometimes say it smells of electricity.

But it is not only during storms that there is electricity in the air. In general, electricity is inherent in the atmosphere, and characterizes its condition. But how and when was this established? At the beginning of the 19th century it was experimentally discovered that a charged conductor ideally insulated from the ground gradually lost its charge. The law of the loss of charge in unit time was established. Later this phenomenon was explained. It was found that the air round us contains charge carriers, charged ions. It is because of them that the conductor ideally insulated from the ground loses its charge.

The charge carrier ions can be charged residues of atoms and molecules, and are divided into light, medium-weight and heavy ions. The macroparticles of fog, raindrops, finely dispersed dust and microorganisms are also charge carriers. In the air surrounding us the charge carriers are in constant motion in all directions. Observations carried out at the earth's surface with a voltmeter with great internal resistance showed that the potential gradient ranges from 120 to 150 V/m.

It has been established through experimental observations that the density of electric charges on the earth's surface is 7×10^5 elementary charges per square kilometre. Knowing the area of the earth's surface it is not difficult to calculate the earth's total charge—it comes to 5×10^7 coulombs. The amount of electricity on the earth's surface is constantly changing. Electric charges move from the earth's surface to the upper layers of the atmosphere and vice versa—from the upper layers of the atmosphere back to the earth's surface. If the movement of the electric charges is expressed in current, the average value is 1500 amperes. This means that a current of 1500 amperes is constantly circulating between the upper layers of the atmosphere and the planet's surface.

In his meteorology course, P.N. Tverskoy points out the various causes of the movement of electric charges, taking as a basis the results of the thorough study of the earth's surface carried out at Cambridge University in England. The data is given in coulombs per square kilometre (on average):

Conduction currents	+ 60
Precipitation currents	+ 20
Lightning discharges to earth	—20
Point effect	—100
Total	—40

It is evident from these figures that the earth's charge is negative, but a certain explanation is necessary. In the first place, the list of the causes of the movement of charges is not complete—there are considerably more charge-carrying mechanisms. In the second place, such a distribution of charges has not been proved theoretically—it is only a hypothesis. But let us go back to the information cited. Conduction currents produced by ions of diverse nature and differing sign move to earth as a whole. During their movement the ions recombine, becoming neutral atoms or molecules, and then again becoming electrically active. In general, it is ions carrying a positive charge that move toward a given spot on the earth's

surface. The same can be said of macrocharged particles precipitated in the form of rain and snow.

The following can be said of the point effect. The earth's surface is not smooth. Much of the irregularity is caused by man in erecting buildings, factory chimneys, etc. During thunderstorms, and at times, long before the storm breaks, when the tension of the electric field in the atmosphere becomes especially high (during thunderstorms, snowstorms, high winds) and there are massive displacements of the air, luminous discharges can be seen on points, sharp angles and various high objects. These discharges are known as St. Elmo's fire. Most frequently this phenomenon occurs in mountains on the sharp tips of protruding rocks, on the tops of trees, at the tops of power line pylons, etc. In lower places the discharges are seen at the tips of lightning rods, the projecting parts of buildings, on wireless aerials, ships' masts and the like. In exceptional cases discharges may occur on animals or on a man's outstretched hand. The phenomenon is accompanied by a crackling sound which may last a few seconds or hours.

Such phenomena are diverse forms of a corona discharge which forms round the luminous object in a sort of halo. They are caused by a sharp increase in the voltage of the electric field to a value a thousand times greater than the average 120-150 V/m. The high voltage of the field causes ionization even at normal pressure, accompanied by the appearance of electrons. Electrons appear as a result of secondary ionisation caused by ions in the air near the point and accelerated by the electric field. As yet, there is no general theory of secondary ionization, but individual elements of this phenomenon are being revealed in experiments. In this respect the works of N.A. Kantsov and V.A. Ragavsky, among others, are extremely interesting and enabled Ya.I. Frenkel to give a sufficiently convincing explanation of secondary ionization and, it follows, of the appearance of negative charge carriers. Frenkel suggests that a point in ionized air should be considered the half of an ellipsoid conductor whose cross section rests on the

earth's surface. Naturally, such an ellipsoid should be under the influence of the earth's field. This assumption enabled Frenkel to calculate the tension of the field at the point. The theoretical results coincided with the results obtained in experiments. Thus, the point effect is the main source of the earth's negative charge.

The fact that lightning discharges bring a big negative charge to earth can also be explained. The lighter charge carriers are naturally in front in the ionized "trunk" of the lightning.

What is it that causes the presence of electricity between the upper layers of the atmosphere and the earth's surface? There are several causes. One was noted by M.V. Lomonosov—static electricity is produced by the friction of the ascending masses of warm air. But that is not all. One of the main sources of atmospheric electricity is in space, beyond the atmosphere. There is a constant radiation flux from sun to earth—ultra-violet and soft X-rays. Radiations differ in density, intensity and energy. On reaching the upper layers of the atmosphere, the ultraviolet and X-rays interact with the atoms and molecules of the air, making them electrically charged. Moreover, multitudes of electrically charged elementary particles of diverse energy are formed. The density of these particles and their number per unit volume differ. At a certain distance from earth solid ionized layers are formed, encircling the earth. The first stable ionized layer is found at a height of 110-120 km; it is relatively thin and has stable boundaries. The next layer is at a height of 180-300 km and has a variable thickness. Besides these permanent electrically charged layers there are floating locally formed areas of charged particles. For the most part it is their presence that explains the sharply changing values of the field potential at different regions of the earth.

It has been established in M.I. Yakovleva's interesting investigation into the effect of the electromagnetic field on animals that some general relationships are common to all species. Moreover, it has been shown that for the existence of each species the presence of an electric field with certain cha-

racteristics is necessary. These characteristics and relationships are undoubtedly associated with one another and relate to the electrical phenomena determining the origin, development and existence of the animate, but as an environmental factor they cannot be considered apart from all the other influencing factors.

2. WHERE IS MAGNETISM AND WHERE ARE THE MAGNETIC FIELDS?

All through this book it has been stressed that everything animate, as well as the medium surrounding man are associated to one degree or another with the movement of charge carriers. Every movement of charge carriers is accompanied by the appearance of a magnetic field. Then why is it that nothing has been said about magnetism up to now?

It has long been known that electricity acts on the animate but as a matter of fact we are only now beginning to learn the nature of that action. The influence of magnetic fields on the animate was discovered a short time ago, in the postwar years to be exact, although people knew about the existence of magnetic fields many centuries ago. Practical use of magnetism began with the compass, a device invented 2000-3000 B.C.

The biological orientation of developing plants, the migration of birds, etc., was discovered long ago. Numerous observations have shown that in the absence of distinct natural or artificial landmarks, animals when freely travelling are directed by the lines of force of the earth's magnetic field. In the 'fifties a scientific explanation of these phenomena began to emerge. This was promoted by the observations of Soviet scientists who found that the germination of maize and wheat varied, depending on the position of the grains relative to the lines of force of the earth's magnetic field. A.S. Presman reports that if the germ root is turned toward the south magnetic pole, grains germinate more quickly than if the root is turned toward the north magnetic pole (the magnetic poles do not

coincide with the geographic poles). Grain arranged perpendicular to the magnetic lines of force germinates worse than when arranged parallel to the lines of force.

Interesting observations have been made in the region round the Kursk magnetic anomaly, a place in the Soviet Union where big deposits of iron ore greatly affect the earth's magnetic field at the surface. Figures for 1964-1967 show that crop yields on farms near the anomaly were 10–15% lower than in districts at some distance from the anomaly, but having the same climatic and soil conditions. It can now be considered proved that the germination and growth of seeds depend on their orientation relative to the earth's magnetic pole when sown.

And now a few words about the ambient magnetic field. The magnetic field in the medium surrounding man and animals is made up of two constituents: (1) the magnetic fields produced by trams, trolleybuses and electric trains, other motors, generators and power transmission lines, etc.; and (2) the earth's magnetic field. A magnetic field is characterized by its potential. The potential of the field from artificial sources at a given locality with a given number of electric installations can only be determined experimentally. The earth's magnetic field is characterized by the horizontal and vertical potential constituents, which can vary.

The earth's magnetic field is likewise characterized by the magnetic declination and the magnetic inclination. The magnetic declination is the angle between the astronomical (geographical) meridian and the magnetic meridian. The astronomical meridian is the direction determining the true position of North and South at a given spot. The magnetic meridian is an imaginary line on the earth's surface coinciding with the direction of the magnetic field. The magnetic inclination is the angle between a horizontal plane and the direction of the potential vector of the magnetic field. The value of the field potential in the International System is taken to be $A/m = 4\pi \times 10^{-3}$ oersted. The magnetic field potential is also measured

in gammas. The oersted is a comparatively large unit, being equal to one million gammas. The sum of the squares of the vertical and horizontal constituents of the earth's magnetic field is equal to the square of the field potential. At the magnetic poles the vertical constituent and the field potential are equal, while the horizontal constituent is equal to zero. At the magnetic poles a freely suspended magnetic needle will assume a vertical position. At the magnetic equator, the horizontal constituent and the field potential are equal. An analytical calculation of the potential of the earth's magnetic field, exclusive of the territory of the poles, gives an approximate value since a number of magnetic anomalies are not taken into account and particularly because of the difficulty of calculating the effect of the magnetic field of the upper layers of the atmosphere.

There is as yet no strict theory of the origin of the earth's magnetic field *. Diverse theories have been suggested at different times, only to be refuted later. Consequently we shall briefly discuss only one hypothesis which is popular today among meteorologists.

In the molten depths of the earth (the core) charge carriers are in motion, which produces eddy currents. The magnetic field of these currents forms the earth's magnetic field which we observe. The displacement of individual closed systems of currents in the core or changes in their intensity cause temporal variations in the magnetic field, observed on the surface as variations over centuries.

This hypothesis was first suggested in 1947 by Ya.I. Frenkel, and was subsequently supported by some foreign physicists.

But the following must be taken into consideration. Charge carriers are also in motion in the atmosphere. This movement is especially strong in the upper layers of the atmosphere,

* Pochtarev, V. I., *Magnetizm Zemli i kosmicheskogo prostranstva* (Magnetism of the Earth and Outer Space), Moscow, 1966.

and specifically, in the ionized layers. The magnetic fields produced by these currents superimposed on the magnetic fields of the eddy currents in the depths of the earth, result in a single, combined electric field on the earth's surface, and it was in this field that life originated and man evolved. The potential of the magnetic field on the earth's surface as a whole is not great—at the poles it comes to 0.3-0.5 oersted. This potential is not constant, but subject to daily, monthly and yearly variations. At times there are sharp increases in the potential. They are caused by sporadic phenomena on the sun, accompanied by intensified solar activity. High fluxes of ultraviolet, roentgen and harder radiation, as well as corpuscular radiation stream from sun to earth. Their interaction with elementary particles in the upper layers of the atmosphere greatly increases the streams of charge carriers, whose magnetic fields increase the earth's magnetic field—a phenomenon called a magnetic storm.

Magnetic storms range in duration from minutes to days and at such times the potential of the earth's magnetic field increases thousands and even tens of thousands of times.

3. MAGNETIC STORMS AND MAN

Investigations conducted between the 'fifties and 'seventies demonstrated the influence of magnetic fields in general and magnetic storms in particular on man. This is set forth convincingly and in due detail in A.S. Presman's monographs, *Elektromagnitnoye pole i priroda* (The Electromagnetic Field and Nature) and *Elektromagnitnye polya v biosfere* (Electromagnetic Fields in the Biosphere). We cite some examples:

In 1930 A.L. Chizhevsky and then others called attention to the connection between the development of certain diseases and processes taking place on the sun. On the basis of statistics over many years he showed a connection between increased solar activity and outbreaks of plague, cholera, diphtheria, grippe and meningitis epidemics, and even epidemics of re-

lapsing fever. British researchers established a distinct growth of neuropsychic disorders during 67 magnetic storms. Statistics covered 40,000 cases.

During 1957-1961 the effect of 7, 14, 21 and 35-day systematic increases in the magnetic potential on the severity of the course of the disease in 30,000 cases was traced. A similar effect was discovered on the development of cardiovascular impairment. In this connection the comprehensive observations of V.M. Gnedushev in Sverdlovsk are of interest. A.S. Presman calls attention to the fact that during periods of heightened solar activity, the multiplication and toxicity of a number of pathogenic bacteria increase; blood clotting is accelerated and the lymphocyte count increases. V. K. Podshebyakin, in Kiev, who investigated a very large number of cases found distinct variations in the amplitude, frequency, and shape of curves of biopotentials during magnetic storms. On the basis of this data he classified people, dividing them into the following five groups: (1) those in whom the biopotential of the brain reacts to the oncoming magnetic storms 3-4 days before its onset; (2) those in whom the biopotential reacts a day before the storm; (3) those in whom the biopotential reacts during the storm; (4) those whose biopotential reacts 2-3 days after the storm; and (5) those whose biopotential does not react (10-15% of the people observed).

An increasing number of people are studying the effect on man of magnetic phenomena in the atmosphere. Reports of investigations involving numerous observations are being published. An article on the results of an investigation carried out by I.E. Ganelina, N.F. Savoyarov and S.K. Churina (I.P. Pavlov Institute of Physiology, USSR Academy of Sciences) was published in *Kardiologiya*, No. 10, 1975, Moscow, under the title "The State of Physical Factors of the Outer Medium and the Frequency of the Principal Complications of Acute Myocarditis". Contrary to existing ideas, the authors show the effect of a lowering of the potential of the magnetic field on the severity of the outcome. The factual material and

the thoroughness of clinical observations convince one of the reliability of the results. Yet the usual statistical method employed by the authors for processing the information did not allow them fully to reveal more complex phenomena from the data at hand. R.M. Arslanova and L.K. Sapozhkov at the Leningrad Institute of Aircraft Instrument Manufacture, processed this data, at the advice of the author, by resolving the curve characterizing the studied dependence into periodic constituents by the method proposed by Walsh in the 'twenties.

Work along this line is continuing at the I.P. Pavlov Institute of Physiology, USSR Academy of Sciences, and at the Leningrad Institute of Aircraft Instrument Manufacture. The investigators hope to reveal the unquestioned possibility of prognosing, and hence of preventing cardiovascular crises.

The facts cited are not exhaustive, but the fact that like conclusions have been drawn by different observers in different countries at different times proves beyond doubt that magnetic fields and magnetic storms have an influence on man.

But through what mechanisms is this influence exerted? Electric fields and electric currents manifest their influence, in one way or another, through their effect on the electric properties of the living body. If the influence of the magnetic field has been established, it can be assumed that the magnetic field has an effect on the magnetic properties of the living body. A distinguishing feature of the action of the magnetic field on the living body is that the body is "transparent" to the field. The vitally important organs are more or less protected by the muscles. Even a hot fire does not immediately lead to a serious outcome. The circulatory system and the muscles, possessing as they do electric conductivity, can shunt, to a certain degree, dangerous current. Penetrating radiation is partially or completely absorbed in the surface areas of the body. Only the magnetic field acts at once on the body as a whole—from the body and organs down to the cells and the individual molecules and atoms.

Are magnetic properties inherent in the animate? The

examples of the influence of magnetic storms on the living organism have necessitated investigations. Carrying out such investigations is made difficult by the fact that magnetic measurement of small values is one of the most difficult fields of measuring technique. It was only in the 'sixties that proton magnetometers possessing sufficient resolution and accuracy appeared. Before that, the principal instrument for measuring magnetic fields was, as a matter of fact, a magnetic needle suspended on a thread, which turned in the direction of the lines of force. The manufacture of iron having great magnetic permeability and the use of new physical phenomena made it possible to carry out the first investigations into the magnetic properties of the living body. The presence of a variable magnetic field originating during the work of the heart muscle was established, and this immediately found practical application. The first models of magnetocardiographs have been designed in the Soviet Union and abroad. Their use in the clinic has demonstrated the possibility of detecting the beginning of serious heart disorders considerably sooner than can be done with the electrocardiograph. Good prospects for the prevention of cardiovascular diseases are opened up, but it will only be possible to talk of them when the magnetocardiograph becomes a simple instrument—in the first models the transducers of input information incorporated coils with several million turns. The small-size magnistors proposed by G. I. Rekalova promise to be of good use in studying the magnetic fields of the living body. The microminiaturization of radio-engineering parts and the manufacture of wire of a few microns in section will enable the designing of instruments for realization of the method of magnetic diagnosis and, possibly, the magnetic therapy of the cardiovascular system.

What are the sources of magnetic fields in the living body and how do these fields react with the magnetic fields of the atmosphere?

First, as to sources. In the first chapters of this book we repeatedly spoke of the movement of charge carriers and the

complex nature of bioelectricity; we noted the most important part played in vital activities by biocurrents produced by migrating electrons and ions. As a first approximation it can be considered that those currents, variable in value, are apparently the sources of the magnetic fields in the living body, and specifically, the magnetic fields of the heart muscle. That shows that bioelectricity is subject to the general laws of electromagnetism—current is produced and varies in value, and magnetic fields are produced and vary in value. Current is produced in a circuit possessing electric conductivity when it is placed in a variable magnetic field. Current is also produced in a circuit placed in a constant magnetic field if the circuit itself is moved. All this is also characteristic of bioelectromagnetism, but the magnetic phenomena undoubtedly reflect delicate and complex phenomena taking place in the living body.

The next step—one that is very promising and extremely difficult—is to study the action of external magnetic fields on man. This should be a comprehensive examination of all environmental characteristics, but particularly electromagnetic phenomena. The importance of such an examination can be illustrated with the following example. L. K. Sapozhkov, under the guidance of the author, studied the possibility of creating a rational biosphere in a closed space. In distinction to the usual conception, this would be an artificially created environment providing optimal conditions for a person's stay and work. While carrying out this investigation a comparative analysis was made of the influence of all the basic factors of the environment on the condition of the cardiovascular system. This was based on the daily number of emergency calls in Leningrad on account of acute heart attacks. This data was compared with the environmental meteorological factors—temperature, humidity, barometric pressure, changes in the barometric pressure and changes in the earth's magnetic field.

Analytical processing of 100,000 emergency calls showed the following: the daily number of calls on account of acute

heart attacks was not constant—at times it increased from day to day by 100–150%. At first it was assumed that the principal factors causing an increase in the number of calls were abrupt changes in barometric pressure or temperature. The point is that diurnal variations in the earth's magnetic field are small, having a range of tens of gammas. Variations in the magnetic field caused by transport and industrial motors and other electric installations are much greater. As a matter of fact it is impossible to measure variations in the magnetic field in cities. All that could be used were the measurements of the magnetic field obtained from the Magnetic-Ionospheric Observatory of the Leningrad branch of the Institute of Terrestrial Magnetism, the Ionosphere and Propagation of Radiowaves, USSR Academy of Sciences. According to L. K. Sapozhkov's algorithm, statistical processing by the method of identification of the process yielded an unexpected result. The number of calls depended on environmental conditions, and its increase was apparently associated with unfavourable changes in these conditions. The most important factors proved to be variations in the magnetic field and sharp changes in the diurnal temperature and barometric pressure when there was a definite correlation with all other environmental conditions. The principal conclusion to be drawn from this investigation is the following. The cardiovascular system has an amazingly delicate sensitivity to variations in the earth's magnetic field and to variations in the frequency constituents of changes in barometric pressure. Experiments on animals kept in magnetic fields of much greater intensity than the terrestrial magnetic field and differing from the latter in the character of variations revealed the influence of these fields on animals but it was different than in man. A survey of people working near sources of magnetic fields as required by their occupations showed that there were complaints of a deterioration in their health but this deterioration was not so acute as in patients attended by the emergency doctor.

From this a general conclusion can be drawn. Bioelectric

and biomagnetic phenomena are indissolubly associated with the electricity and magnetism of the surrounding medium and with all its physical characteristics. Study of these relationships holds out excellent prospects of gaining knowledge of animate matter, and what is most important, the prospect of being able to regulate environmental conditions and provide optimal conditions for man's life and activity.

The founder of the new trend in the science of man's environment, ratiobiospherology, can rightly be considered the outstanding naturalist, Academician Vladimir Ivanovich Vernadsky.

4. ELECTRICITY AND THE RATIOBIOSPHERE

Electricity and magnetism were actively involved in man's evolutionary development. Both are part of the biosphere. But what is the biosphere?

The word, "biosphere", appeared in the literature at the beginning of the 19th century. It was that word the French naturalist, Lamarck, used for "the region of the existence of the animate". At the end of the 19th century the Austrian geologist, Eduard Suess, extended the concept of the biosphere to include geology, pointing out that minerals owe their origin, to a great extent, to the physico-chemical energetic processes of the animate world. The biosphere as the region of the existence of the animate, in the Lamarckian understanding, is used in the literature to this day. It is so defined even in the latest edition of the *Bolshaya Sovetskaya Entsiklopediya* (The Great Soviet Encyclopedia) in the section on cosmonautics.

In 1926 Vernadsky defined the word differently. He said the biosphere was not the region of the existence of the animate but the conditions and factors in the environment in which, thanks to the interconnected and interdependent variations of these conditions and factors, terrestrial life originated and exists. Vernadsky made this statement: "Mankind as a whole is becoming a powerful geological force, and before

it, in its thoughts and work, arises the question of remaking the biosphere in the interests of free-thinking man as a single whole". He developed this idea. The medium surrounding man is not always favourable for his existence—it can and should be reconstructed in man's interests. But this interpretation of the biosphere has not been widely accepted, and the less fortunate concept of the biosphere as the region of habitation is used instead.

In line with Vernadsky's teaching about the biosphere, the term "ratiobiosphere" ("ratio" is used here in the sense of the Latin word—reason) is to be understood as an artificial medium surrounding man which makes his life easier by providing optimal conditions for his work and stay. Modern conditions are quite different from the conditions of work and everyday life a hundred years ago. The proportion of the earth's surface covered by forest and that covered by vegetation has changed; the amount and spectrum of radiation has also changed, as has the moisture cycle—evaporation from the earth and precipitation in various forms. The most significant changes in the medium began at the end of the 19th century when technology began to play an active role in man's life. The air is being contaminated with waste gases from the fuel burned in aircraft and with industrial wastes; variations in electromagnetic fields are increasing because of the increasing number of radio stations.

The change in the environment was first manifested in the change in the microflora and the intensity of the electric fields interacting with man. The change in the environment first affected people's sight and hearing. The excess during the day of bright artificial illumination with a spectrum unlike that of sunlight has lowered sensitivity of vision in urban dwellers as compared to that of people living in rural districts. Here is a characteristic example. A little more than 100 years ago, the stage of the Mariinsky Theatre in St. Petersburg, today the S. M. Kirov Academic Theatre of the Opera and Ballet, was lighted with 40 or 50 kerosene lamps arranged along the

outer perimeter of the stage, and there were no complaints about the lighting. Today the stage is lighted with powerful floodlights from the side boxes, and there is also bias lighting from the sides; the back of the stage is lighted separately, and yet the audience often complain that the stage is dimly lighted.

The need for bright illumination is not limited to the theatre. It was not without reason that during the last 20 years State Standards for obligatory illumination have twice been raised. The lowering of the sensitivity of the visual analyzer which determines the value of the electric impulse transmitted to the central nervous system is unquestionably undesirable, but at the same time this lowering of the electrical activity of the visual analyzer is in its way the body's defensive reaction to the heightened action of visual stimuli, an adaptation to them.

Modern turbojet and jet planes take people from one climatic zone to another in a few hours time. These people must be, and in many cases must work, in conditions radically different from those in which they were only a few hours before. The intensity of electromagnetic fields is one of the characteristics of the environment which are changed. There is no gradual adaptation to the surrounding medium which is the case when travelling in a train which covers this distance in several days. One naturally wonders if it is possible to accelerate adaptation to the medium. The results of investigations show that it can be done. Studies along this line are being conducted on the basis of ratiobiospherology.

Ratiobiospherology is the science of an artificial habitable environment providing optimal conditions for a person's stay and work. This definition is repeated deliberately, since ratiobiosphere is often confused with microclimate. The microclimate in dwellings, industrial spaces and airplane cockpits and passenger compartments is intended to maintain or produce a number of characteristics equivalent to the climate of a forested area in central Russia or the Black Sea coast. It is becoming evident from experience, firstly, that the external medium produced by present-day air-conditioning installations

does not reproduce the natural environment completely with all its desirable characteristics, and secondly, that a climate, an environment, excellent for holiday-making does not always provide optimal conditions for work.

What characterizes the environment? For a long time it was considered that the basic characteristics of a habitable environment were the following: standard oxygen/nitrogen composition of the air; temperature of 18—25°C; relative humidity of 60–80%; barometric pressure of 760 mm Hg (1033 mbar); constant spectral composition of electromagnetic radiation in the visible region of the spectrum. Such an environment originated about a million years ago when an equilibrium was established between plants and living organisms requiring oxygen. It is such an environment that air-conditioning is intended to produce. Until recently the basic characteristics enumerated above were sufficient for providing an artificial environment in production spaces and dwellings. It was mentioned earlier that the atmosphere is now contaminated with wastes from industrial enterprises and aircraft. The time has come when these contaminants must be taken into account, as well as other environmental factors acting on man, particularly electromagnetic fields.

The diagram in Fig.5 characterizes a ratiobiosphere. It can be seen from the diagram that there are considerably more factors acting on man than those enumerated above. When creating a life support system or an artificial climate system, which is the same thing, they should all be taken into account in one degree or another. At present this is impossible. Usually sanitary-hygienic investigations along this line are limited to studying the effect of a single factor or two factors simultaneously, irrespective of other factors. It is now becoming evident that a person's reaction to a change in the environment depends on the action of the entire factor complex. For example, the action of temperature and humidity on a person is not the same for different intensities of magnetic and electric fields. Unfortunately, there are as yet no combined measur-

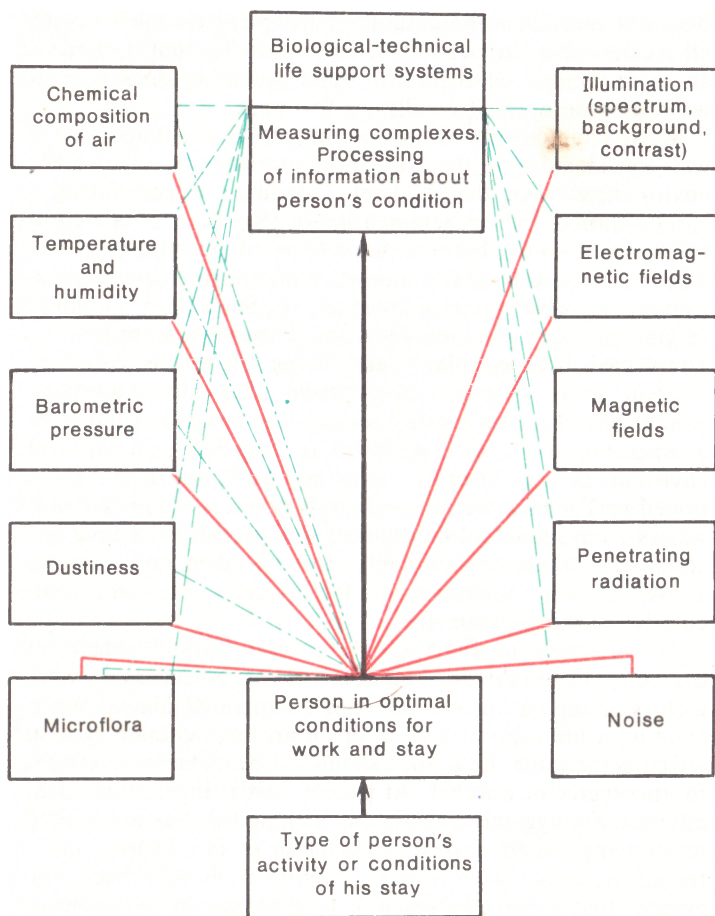


Fig. 5. Diagram of ratiobiosphere in life support system

These continuous lines indicate environmental factors acting on man; broken lines, factors necessary for regulating life support systems; dot-and-dash lines, factors in life support systems amenable to regulation

ing systems for assessing a person's reaction to a change in the environment. And probably opinions still differ when assessing the optimal combination of characteristics for a person's stay. Also, there are as yet no systems of artificial climate with interconnected regulation of at least five or six external characteristics, while taking a person's reaction into account. But there will be! There is sure to be! So far, investigations along this line are being conducted to ensure safe flight in advanced aircraft and spaceships, and also to provide conditions for work in special industrial spaces. The effect of an artificial environment on man and any living organism will be manifested directly and indirectly in changes of one kind or another in electrical activity. Consequently these changes can become a means of assessing the optimization of the environment.

When creating an artificial atmosphere a moral problem arises, associated with the choice of characteristics. Assume that a composition of the atmosphere is found which makes it possible for a person to work harder for a short time or even for a lengthy period, and which also increases the resolving power in the perception of information. This is all well and good but the average life span will be shortened. On the contrary, if conditions of physical comfort are provided, the average life span can be maintained or even increased, but the body can no longer be overloaded in situations of strain. There are other possibilities. What is the solution? One thing is certain — all requirements must be satisfied as fully as possible. Optimization of the gaseous medium, temperature and humidity is not sufficient. All factors shown in Fig. 5 must be taken into account. This can be done in the following way. The rectangle in the centre of the diagram indicates a person's condition brought about by the environmental factors enumerated in rectangles to the right and left. A general assessment of a person's condition is obtained by means of instruments characterizing the condition, e.g., the instrument described in Chapter 5. The condition is determined by a summarizing instrument

of one kind or another. A signal from this summarizing instrument which does not as yet exist, is transmitted to systems regulating changes in characteristics, thus creating an environment providing optimal conditions for a person's work and stay. This system of adjusting the environment is conceived as a system summarizing assessments of one person and of a group of people present in a closed space. Future investigations in this field will show that electricity and magnetism act on a person not only directly but also through other factors, such as the microflora.

The microflora is characterized by the word, "bioaerosol". The bioaerosol consists of various microorganisms—bacteria, viruses and fungi (moulds). They exist in the air, depending on the conditions of the environment. The microflora reacts most quickly to changes taking place in the atmosphere, including variations in its electromagnetic properties. Microorganisms, like all living organisms, need a gaseous medium, food, support for reproduction, and electromagnetic fields. Food consists of various chemical substrates, and the support for reproduction is dust (nonmetallic), the skin of a living organism, insulating materials, wood, paper, etc. In the presence of people the number of microorganisms sharply increases. The products of man's vital activity are excellent food for them. In the air many of them assimilate carbon dioxide, oxygen and admixtures necessary for the synthesis of proteins. As a result of the activity of microorganisms intermediate chemical substances are formed, such as hydrogen, formic acid and other organic compounds. Microorganisms are extremely sensitive to electromagnetic radiation outside the visible region of the spectrum, their reaction being shown in their reproduction and in changes in their characteristics as a species. Investigations carried out by E. N. Chistyakova, Yu. V. Pankratov, S. E. Manoillov, V. F. Kondratyeva and N. B. Ivanova showed that changes take place in microorganisms under the action of electromagnetic fields. Some of them die, while in others there are changes in hereditary properties. Geomagnetic va-

riations also affect them. Microorganisms are necessary for human life. Whereas some are dangerous, many are necessary for man's existence. Regulating the number and species of microorganisms in the air is an important task to be tackled when setting about the creation of a ratiobiosphere.

I would like to finish this chapter with a quotation from V. I. Vernadsky: "A new geological phenomena has appeared on our planet. Man can and must through his labour and thought remake the sphere of his life, remake it radically compared to what it was before. More and broader opportunities are opening up before him, and perhaps the generation of my grandchildren will approach their full realization... Today we are going through a new evolutionary development of the biosphere. What is important for us is that the ideals of our democracy are in unison with the spontaneous geological process, with the laws of nature. For that reason we can look confidently to the future. It is in our grasp and we will not relinquish our hold."*

* Vernadsky, V. I., *Biosfera* (The Biosphere), Moscow, 1967, p. 358.

CHAPTER FOUR

Items from the Prehistory of the Use of Electricity in Medicine

1. FIRST DISCOVERIES

Since ancient times people have endeavoured to understand natural phenomena. Many brilliant hypotheses about the natural occurrences around man have appeared in different countries and at different times. The ideas of Greek and Roman scholars and philosophers living before our era—Archimedes, Euclid, Lucretius, Aristotle, Democritus and others—even now are of help in the development of scientific research.

The first information about electricity and magnetism is of interest for the subject, "Electricity and Man". It comes from Miletus, an ancient trading city on the Mediterranean, and the author is the philosopher, Phales (end of 7th and beginning of 6th century B. C.). He described electric phenomena—how amber, when rubbed, attracted bits of cloth, thread and paper. He also described magnetic phenomena. Phales of Miletus can be considered the founder of the science of electricity. Phales's pupils accumulated crumbs of information about electricity, which in one way or another was associated with living organisms and man. Thus in ancient times it was known that certain species of fish possessed electric properties, and such fish were even employed in healing. Thirty years before our era Dioscorides healed gout and chronic headache by means of electric shock from touching an electric eel. In

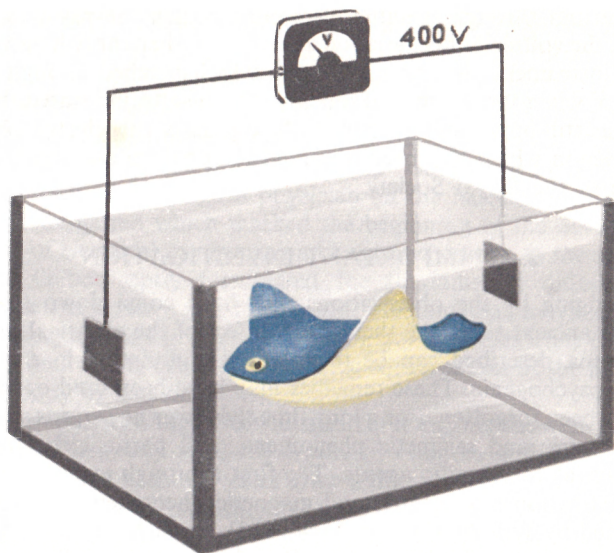


Fig. 6. Experiment with electric ray

Russian chronicles of the 14th century there are entries which show that this remarkable healing agent was also known to the Russians. Marvellous fish are described which when put in a cask have a healing effect when touched.

After the first observations of electric and magnetic phenomena by Phales of Miletus, interest in them sprang up from time to time in connection with curing.

It should be noted that the electric properties of certain fish which were known in ancient times have remained to this day an unsolved mystery. Thus, for instance, in 1960 at an exhibition in London organized to mark the tricentenary of the founding of the Royal Society among the puzzles of nature still to be solved, a glass aquarium containing an electric ray was demonstrated (Fig. 6). A voltmeter was connected to the

aquarium through metallic electrodes. When the ray was at rest, the voltmeter needle stood at zero, but when the fish moved the instrument showed a potential which reached as high as 400 V when the ray moved quickly. The inscription stated that it was still impossible to explain the nature of this electric phenomenon which had been observed long before the organization of the Royal Society.

2. AN IMPORTANT INVESTIGATION

Judging by the observations that have come down to us from ancient times the therapeutic effect of the electrical phenomena described can be regarded as stimulating in a way and psychogenic. These remedies may have been used or may have been forgotten. For a long time there was no serious study of electric and magnetic phenomena, and particularly, their action as therapeutic agents. The first thorough experimental investigation into electric and magnetic phenomena was conducted by William Gilbert (1544-1603). English physician and physicist, later physician to the Royal household. Gilbert was an innovator in medicine. His success was largely due to his serious study of ancient remedies and then employing them. This included electricity and magnetism. Gilbert realized that without a detailed study of electric and magnetic radiation it would be difficult to use these "fluids" in treatment.

Rejecting fantastic, unverified conjectures and unfounded assertions, Gilbert carried out diverse experimental studies of electric and magnetic phenomena. The results of these studies, the first of their kind, were stupendous.

In the first place, Gilbert was the first to advance the idea that the magnetic needle of the compass moves under the influence of the earth's magnetism, and not under the action of the North star, as had been assumed before. He was also the first to carry out artificial magnetization, and to establish the fact that the magnetic poles are inseparable. Gilbert studied electric phenomena as well as magnetic, and on the basis of

numerous observations showed that amber was not the only material that produced electric radiation when rubbed. Nevertheless, since amber was the first material that was observed to be electrified on rubbing, he proposed that all these materials should be termed electric from the Greek word "electron" (amber). So the word "electricity" came to be used at the suggestion of the English physician on the basis of his historic investigation which marked the beginning of the development of electrical engineering and electrotherapy. At the same time Gilbert aptly formulated the fundamental difference between electricity and magnetism. He said that magnetism, like weight, was a prime force coming out of bodies while electricity was due to special fluids being squeezed out of the pores of a body by friction.

As a matter of fact, electrification and magnetism were considered separately until the works of Ampere and Faraday, i.e., over two hundred years after Gilbert's death (the results of his work were published in 1600 in a book, *De magnete, magneticis que corporibus, et de magno magnete tellure* (On the Magnet, Magnetic Bodies, and the Great Magnet, the Earth)). In his "History of Physics"*, P. S. Kudryavtsev quotes Galileo, the great astronomer and physicist of the Renaissance: "I bestow my praise, I am filled with wonder and I envy Gilbert. He developed amazing ideas about a subject which so many gifted people had discussed but which was not carefully studied by any of them. I am convinced that in time this field of science (electricity and magnetism—V. M.) will achieve successes as a result of fresh observations, and especially, as a result of strict measures of proof".

* P. S. Kudryavtsev's *Istoriya fiziki* (History of Physics) (in 2 vols.), one of the few fundamental monographs on the subject, was of considerable assistance to the author in writing the prehistory of the development of the topic, "Electricity and Man". The following quotations in discoveries in physics were taken from this work of Kudryavtsev.

Gilbert died on November 30, 1603, bequesting all his instruments and papers to the Royal College of Surgeons, of which he was President until his death.

3. THE PRIZE AWARDED TO MARAT

We come now to the eve of the French Revolution. Let us summarize investigations into electricity carried out at that period. The existence of positive and negative electricity had been established. The first electrostatic machines had been constructed and improved. Leyden jars (condensers for static electricity) had appeared, as well as electroscopes; hypotheses about electrical phenomena had been formulated; daring attempts had been made to study the electricity of lightning.

The electrical nature of lightning and its action on people strengthened the opinion that electricity could both kill and cure people.

We will cite some examples. On April 8, 1730, two Englishmen, Grey and Wheeler carried out an experiment with an electrified person which is now a classic. Two dry posts were sunk upright in the yard of Grey's house. A wooden bar was secured between the tops of the posts. Two lengths of hair rope were thrown over the bar and the lower ends fastened. The ropes easily stood the weight of a boy who agreed to take part in the experiment. Lying on the loops of rope like swings, the boy held in one hand a rod which had been electrified by friction or a metal rod which conducted electricity from an electrified object. In his other hand the boy held a number of coins which he dropped one by one into a metal dish on a dry board on the ground below him (Fig. 7). The coins received a charge through the boy's body and as they fell into the metal dish, the dish gradually became electrified and began to attract dry straws laid out around it. Experiments were repeated many times and attracted much interest which was not confined to scientists.

The Frenchmen, Du Fay and Nollet, and the Russian, Ge-

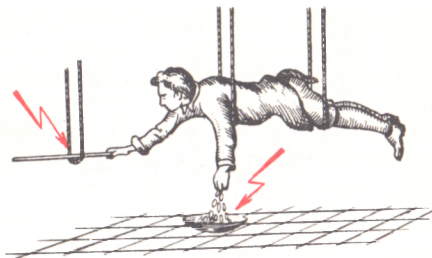


Fig. 7. Electrification experiment

org Rikhhmann, almost simultaneously and independently of one another designed an instrument for measuring the degree of electrification. This considerably extended the use of electric charges for medical treatment since it had become possible to measure the dose. The French Academy devoted several sessions to discussions on the effect on man of discharges from Leyden jars. Louis XV also became interested in this. At his request, Nollet together with the physician, Louis-Guillaume Le Monnier carried out an experiment in one of the big halls of the Versailles palace, demonstrating the perforating action of static electricity. Some good came of the court amusements—many people became interested and many began to study electrification phenomena.

In 1787 the English physician and physicist, Adams, built the first electrostatic machine designed specially for therapeutic purposes, and made wide use of it in his medical practice (Fig. 8). He obtained favorable results which can be explained by the stimulating effect of the charge, the psychotherapeutic effect and the specific action of the charge.

The epoch of electrostatics and magnetostatics to which everything described above belongs ended with the elaboration of the mathematical fundamentals of these sciences performed by Poisson, Ostrogradsky and Gauss.

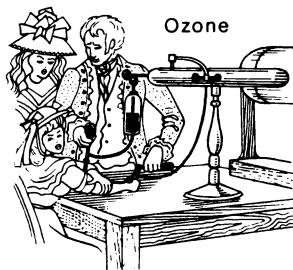


Fig. 8. Electrotherapy (18th century engraving)

The use of electric charges in medicine and biology was fully recognized. Muscular contraction caused by touching electric rays, eels, and catfish was evidence of the action of an electric shock. Experiments by the Englishman, John Warlish, proved the electric nature of the shock from the ray, and anatomist, Hunter, gave an exact description of the ray's electric organ.

In 1752 Sulzer, a German physician, published a report of a new phenomenon he had discovered: when the tongue touched two different metals simultaneously, a sour taste was produced. Sulzer did not suspect that his observation marked the beginning of two most important sciences—electrochemistry and electrophysiology.

Interest in the use of electricity in medicine grew. The Rouen Academy announced a competition for the best paper on the extent and conditions under which it was possible to rely on electricity in treating diseases. The first prize was awarded to Marat, a physician, whose name has gone down in history as one of the leaders of the French Revolution. The appearance of Marat's paper was timely, since the use of electricity for medical treatment was often associated with mysticism and quackery. A certain Mesmer, seizing upon fashionable scientific theories about spark-emitting electric machines, began to

claim that in 1771 he had discovered a universal medical remedy—"animal magnetism"—which acted on patients at a distance. He opened special medical rooms furnished with electrostatic machines of fairly high voltage. The patient was told to touch the charged parts of the machine, on doing which he received an electric shock. Apparently instances in which a favourable effect was obtained from Mesmer's treatment can be explained not only by the stimulating effect of the electric shock but also by the bactericidal effect of the ozone in the rooms where the electrostatic machines were operated. But Mesmer had no idea of this. After a number of cases of unsuccessful treatment with serious consequences, of which Marat had warned, Mesmer disappeared from France. A Government commission which was set up to investigate Mesmer's "doctoring", and which included Lavoisier, the outstanding French chemist, was unable to explain the favourable action of electricity on people. For a time treatment with electricity ceased in France.

4. DISPUTE BETWEEN GALVANI AND VOLTA

And now we come to experiments carried out almost two hundred years after the publication of Gilbert's work by the Italian, Luigi Galvani, Professor of anatomy and medicine, and the Italian, Alessandro Volta, Professor of physics.

Luigi Galvani carried out an experiment in the anatomy laboratory of Bologna University, the description of which astounded scientists throughout the world. Frogs were being dissected on the laboratory desk. It was the object of the experiment to demonstrate and observe the nerves of the extremities. An electrostatic machine used for producing and studying sparks, stood on the same desk. Galvani describes what happened in his work, "The Force of Electricity in Muscular Movements": "By accident, one of my assistants very slightly touched the inner femoral nerves of the frog with his scalpel.

The frog's leg jerked sharply... this only happened when a spark was drawn from the condenser of the machine”.

This phenomenon can be explained in the following way. A varying electric field acts on the atoms and molecules of the air in the spark zone, and as a result they acquire electric charges and are no longer neutral. The ions and charged molecules are disseminated to a relatively short distance from the electrostatic machine since in their movement they collide with the molecules of the air and lose their charges. They can also accumulate on metal objects which are well insulated from the surface of the ground, but are discharged if an electric circuit is formed on the ground. The floor in the laboratory was wooden and dry, and insulated the room where Galvani was working from the ground. The object on which the charges accumulated was a metal scalpel. When the frog's nerve was only lightly touched with the scalpel the charges accumulated on the scalpel were discharged, causing the leg to jerk without any mechanical damage. It was already known at that time that a secondary discharge could occur through electrostatic induction.

Galvani was a brilliant researcher and during one of his numerous diversified experiments he discovered another phenomenon which was of great importance in the subsequent development of electrical engineering. This discovery was made while he was studying atmospheric electricity. We quote Galvani again: ... “Exhausted... with fruitless waiting... I began... to press the copper hooks stuck into the frog's spinal cord against the iron grating and the frog's legs contracted.” This experiment which was not performed in the open air but in a room where there were no electrostatic machines showed that when a frog's body is touched simultaneously with two different metal objects—wire and plate of copper, silver or iron—the muscles contract in the same way as when touched with an object charged by an electrostatic machine. No one had observed this phenomenon before. On the basis of his observations he drew a bold conclusion: there was another

source of electricity—"animal electricity"*; the live muscle was a condenser like a Leyden jar, and positive electricity accumulated inside it; the frog's nerve was an inner "conductor". Connecting two metal conductors to the muscle caused the appearance of an electric current which, like the spark from an electrostatic machine, caused the muscle to contract. Galvani confined his experiments to frogs, and perhaps it was for that reason he proposed using the frog's leg for measuring amounts of electricity. The measure of electricity was the activity of the rise and fall of the leg when brought into contact with a metal plate which simultaneously touched a hook passing through the frog's spinal cord, and the frequency with which the leg rose per unit time. For some time even eminent physicists, among them Georg Ohm, used a physiological indicator of this type.

On the basis of Galvani's electrophysiological experiment, Alessandro Volta designed the first electrochemical source of electric energy, which in turn opened a new epoch in the development of electrical engineering.

Alessandro Volta was one of the first to appreciate Galvani's discovery. He carefully repeated Galvani's experiments and obtained much information confirming Galvani's results. But in his first articles, "On Animal Electricity" and in his letter of April 3, 1792, to Doctor Boronio, Volta, unlike Galvani who considered the phenomena noted from the positions of "animal electricity", centred attention on chemico-physical phenomena. Volta established the importance of using different metals (zinc, copper, lead, silver and iron) between which was placed a cloth moistened with acid.

Here is what Volta wrote: "In Galvani's experiments the source of electricity is a frog. But what is a frog or any animal in general. Primarily, it is nerves and muscles and in them various chemical compounds. If the nerves and muscles of a

* Later in the text the term "animal electricity" is replaced by the equivalent "electrical activity of living tissue".

dissected frog are connected to two different metals, an electric action appears when this circuit is closed. In my last experiment there were also two metals—stanniol (lead—*V. M.*) and silver, and the liquid was saliva. By closing the circuit with a connecting plate I provided conditions for the electric fluid to move from one place to another, but couldn't I simply immerse these same metal objects in water or in a liquid like saliva? What has "animal electricity" got to do with it?"

Volta's experiments lead to the conclusion that the source of electric action is a circuit of unlike metals in contact with a damp cloth or one moistened with acid.

In one of his letters to his friend, Vazagi, a physician (another example of physicians' interest in electricity), Volta wrote: "I have long been convinced that the entire action comes from metals—when they come into contact the electric fluid enters a damp or watery body. On these grounds I consider myself justified in ascribing all the new electric phenomena to metals, and replacing the term "animal electricity" by the term "metallic electricity".

Volta considered frog's legs nothing more than a sensitive electroscope.

This started the historic dispute between Galvani and Volta and their followers about "animal" and "metallic" electricity.

Galvani adhered to his view. He excluded all metal from his experiment and even dissected frogs with glass knives. It turned out that even in such an experiment there was contraction when the frog's femoral nerve was brought into contact with the muscle but the contraction was considerably less than when metals were involved. This was the first demonstration of bioelectric phenomena which are the basis for modern electrodiagnosis of disorders of the cardiovascular and other systems.

Volta attempted to discover the nature of the unusual phenomena, and precisely formulated the problem confronting him: "What is the cause of electricity, I asked myself, just as any of you would do. Thinking it over brought me to the con-

clusion: when two different metals, such as silver and zinc, are brought into contact, the equilibrium of the electricity in both metals is upset. At the point of contact positive electricity moves from the silver to the zinc and accumulates there, while negative electricity, in the same way, accumulates on the silver. This means that electrical substance moves in the definite direction. When I place plates of silver and zinc, one on the other without anything between, that is the zinc and silver are in contact, their combined action comes to zero. To increase the electric effect, or combine it, each zinc plate should be in contact with a single silver plate, and successively stack up as many pairs as possible. I do this by placing a piece of wet cloth, separating it in this way from the silver plate of the next pair". A far-sighted statement. Much of what he said has not lost its significance today from the standpoint of modern views.

Unfortunately this dispute was tragically broken off. Napoleon invaded Italy. For refusing to swear allegiance to the new government, Galvani lost his chair at the University, was discharged and soon died. Volta lived to see the complete recognition of the discoveries of both scientists. In their historic dispute both had been right. The biologist, Galvani, has gone down in history as the founder of bioelectricity; the physicist, Volta, is recognized as the founder of electrochemical sources of current.

5. V. V. PETROV'S EXPERIMENTS. THE BEGINNING OF ELECTRODYNAMICS

The first stage of the science of "animal" and "metallic" electricity ends with the work of Academician V. V. Petrov, Professor of Physics at the Medico-Surgical Academy (now the S. M. Kirov Military-Medical Academy in Leningrad).

Petrov's work had great influence on development of the use of electricity in medicine and biology in Russia. He orga-

nized a physics laboratory at the Academy which was furnished with excellent equipment. There he constructed a high-voltage electrochemical source of electric energy, the first of its kind in the world. Judging by the number of elements in it, the voltage must have been as high as 1800-2000 V with a capacity of 27-30 W. Using this multi-purpose source, Petrov was able in a short period to carry out scores of investigations which revealed diverse ways of employing electricity in a number of fields. Petrov's name is usually associated with the appearance of a new source of illumination, electricity, on the basis of the effective electric arc he discovered. In his monograph *Izvestiye o galvanii-voltovskikh opytach* (Report on Galvanic-Voltaic Experiments), published in 1803, Petrov set forth the results of his investigations. This was the first book on electricity published in Russia. It was republished in 1936.

This book is important not only for investigations relating to electrical engineering, but also for the results of the study of the interconnection and interactions of electric current with the living organism. Petrov showed that the human body is capable of electrification and that the galvanic-voltaic battery consisting of a large number of elements is dangerous for man; as a matter of fact he foretold the possibility of employing electricity for physiotherapeutic treatment.

Petrov's experiments had a great influence on the development of electrical engineering and medicine. His "Report on Galvanic-Voltaic Experiments" is to be found in the Latin translation and in Russian in the national libraries of many European countries. The electrophysical laboratory he organized enabled scientists at the Academy to carry out extensive studies in the middle of the 19th century on the use of electricity for medical treatment. In this line of research, the Military-Medical Academy held a leading place among institutes in Russia and also in European countries. Suffice it to name Prof. V. P. Egorov, V. V. Lebedinsky, A. V. Lebedinsky, N. P. Khlopin and S. A. Lebedev.

What was the 19th century's contribution to the study

of electricity? In the first place an end was put to the monopoly of electricity by medicine and biology. This began with the work of Galvani, Volta and Petrov. The first half and middle of the 19th century were marked by important discoveries in electrical engineering associated with the names of the Dane, Hans Oersted; the Frenchmen, Dominique Arago and André Ampère; the German, Georg Ohm; the Englishman, Michael Faraday; and the Russians, Boris Yakoby, Emil Lenz and Pavel Shilling.

We will briefly discuss the most important of these discoveries which directly concern our subject.

Oersted was the first to establish the interconnection of electric and magnetic phenomena. While experimenting with galvanic electricity (the term then used for electricity from electrochemical sources to distinguish from electricity produced by electrostatic machines), Oersted noticed the deflection of the needle of a compass near a galvanic battery at the moment the circuit was closed or broken. He found that this deflection depended on where the compass was placed. It is greatly to Oersted's merit that he himself realized the importance of his discovery. The idea that electric and magnetic phenomena were unrelated—an idea based on Gilbert's work which for over 200 years had seemed unshakeable—was shattered. Oersted obtained reliable experimental data on the basis of which he wrote and later published a book, "Experiments Relating to the Action of the Electrical Conflict on the Magnetic Needle". He briefly formulated his discovery in these words: "Galvanic electricity moving from north to south over a freely suspended magnetic needle deflects its northern end to the east, and when moving in the same direction under the needle, deflects it to the west".

André Ampère, French physicist, revealed the essence of Oersted's discovery, the first reliable evidence of the interrelationship of electricity and magnetism. Ampère was an unusually versatile scientist and scholar, an outstanding mathematician and keenly interested in chemistry, botany and an-

cient literature. He was an excellent popularizer of scientific discoveries. His contribution to physics was the creation of a new branch of that science, *viz.*, electrodynamics, embracing all manifestations of moving electricity. Ampère's source of moving electric charges was a galvanic battery. On closing the circuit he obtained the movement of the charges. Ampère showed that electric charges at rest (static electricity) did not act on the magnetic needle, did not deflect it. Using modern language, it can be said that Ampère revealed the significance of transitional processes (closing the electric circuit).

Michael Faraday completed what Oersted and Ampère had begun by elaborating, concisely and logically, the principles of electrodynamics. He also made a number of major discoveries independently, which unquestionably had a great influence on the use of electricity and magnetism in biology and medicine. Faraday was not a mathematician like Ampère, and in his numerous publications used not a single analytical expression. But the lack of analytical analysis was compensated by Faraday's ability as an experimenter, his industry and conscientiousness. It was he who discovered the law of induction. He said he had found a way of converting electricity into magnetism and vice versa. He also discovered self-induction.

Faraday's crowning achievement was the discovery of the laws governing the passage of electric current through a conducting liquid and chemical decomposition of the latter under the action of the current (the phenomenon of electrolysis). He wrote that the amount of substance on the conducting plates (electrodes) immersed in the liquid depended on the strength of the current and on the duration of its passage—the stronger the current and the longer it was passed through the liquid, the greater the amount of substance that separated from the solution (basic law of electrolysis).

Russia was one of the countries where the discoveries of Oersted, Arago, Ampère and, especially, Faraday were developed and found practical application. Making use of the

discovery of electrodynamics, Boris Yakoby designed the first ship with an electric motor. Emil Lenz carried out a number of studies of great practical importance in various fields of physics and electrical engineering. His name is usually associated with the elaboration of the law of the heat equivalent of electric energy known as the Joule-Lenz law. He also established the law called by his name.

This ends the period in which the fundamentals of electrodynamics were elaborated.

6. USE OF ELECTRICITY IN MEDICINE AND BIOLOGY IN THE 19TH CENTURY

P. N. Yablochkov arranged two carbons parallel to each other and separated by a fusible lubricant, thus producing an electric candle—a simple source of electric light capable of illuminating a room for several hours. Yablochkov's candle held for three or four years, finding application in almost all countries until it was replaced by the longer-liver incandescent lamp. Electric generators were being designed everywhere and accumulators were also widespread. The use of electricity in chemistry initiated by Michael Faraday was becoming popular.

The transfer of matter—the movement of charge carriers—was one of the first electrical phenomena to find application in medicine for introducing medicinal compounds into a patient's body. The essence of the method consists in the following. A piece of gauze or some other cloth is moistened with the necessary medicinal compound and is used as a pad between the electrodes and the patient's body. The electrodes are connected to a source of direct current. This method began to be used during the second half of the 19th century and is still extensively applied. It is known as electrophoresis or ionophoresis. The reader will learn about the practical employment of electrophoresis in Chapter Five.

Another discovery in electrical engineering followed which

was of the greatest importance for practical medicine. On August 22, 1879, Sir William Crookes, English chemist and physicist, reported on his studies of cathode rays, of which the following became known at that time:

1. When a high-voltage current is passed through a tube containing a highly rarefied gas, a stream of particles moving at an immense speed is emitted from the cathode.
2. The motion of these particles is strictly rectilinear.
3. This radiant energy can produce a mechanical action, e.g. it can rotate a small impeller set in its path.
4. The radiant energy is deflected by a magnet.
5. Heat is developed at places where the radiant matter falls. If the cathode is made in the form of a concave mirror, even such high-melting substances as an alloy of iridium and platinum can be fused in its focus.

6. Cathode rays are a stream of material particles smaller than atoms, viz., particles of negative electricity.

Such were the first steps on the threshold of the new and momentous discovery by the German physicist, Wilhelm Roentgen.

Roentgen found a new type of radiation which he called X-rays. Later these rays began to be called roentgen rays. Roentgen's report caused a sensation. Numerous laboratories in all countries began making apparatus to produce X-rays and Roentgen's experiments were repeated and developed. This discovery aroused particular interest among physicians. Physics laboratories with X-ray installations were besieged by physicians and their patients who suspected that there were metal objects somewhere in their bodies, such as needles or buttons they had swallowed. Never before in the history of medicine had a discovery in electricity found practical application so quickly as this new means of diagnosis — roentgen rays.

There was immediate interest in roentgen rays in Russia. Even before scientific publications appeared, before there was any exact information about the apparatus but only a

brief communication on Roentgen's paper, Alexander Stepanovich Popov, the inventor of radio, was at work at Kronshadt near St. Petersburg making the first Russian roentgen apparatus. Little is known about this. Popov's role in designing the first Russian roentgen apparatuses became more widely known from F. Veitkov's report. This was aptly supplemented by Popov's daughter, Ekaterina Kyandskaya-Popova, in an article entitled "Inventor of the Radio and X-rays" published in collaboration with V. Tomat in *Nauka i zhizn*, No. 8, 1971.

Further advances in electric engineering provided greater opportunities for studying "animal electricity". By that time the galvanometer had been designed, and using it, Matteucci demonstrated that during the vital activity of muscles an electric potential is developed. Matteucci severed a muscle transversely to the fibres and connected the cut end to one of the poles of a galvanometer; when the longitudinal surface of the muscle was connected to the other pole, the galvanometer showed a potential ranging from 10 to 80 mV, the value depending on the type of muscle. Matteucci claimed that the biological current "flowed" from the longitudinal surface to the transverse cut and that the cut was electronegative. This curious fact was confirmed by experiments on different animals — tortoise, rabbit, rat and birds — carried out by a number of researchers, of whom special mention should be made of the German physiologists, Du Bois-Reymond and Hermann, and the Russian, V. Yu. Chagovets. In 1834 Peltier published the results of an investigation on the interaction of biological potentials and direct current passing through living tissue. He found that in such cases the polarity of the biological potentials changed as did the amplitudes. Changes in physiological functions were likewise observed.

Electrical measuring instruments with adequate sensitivity and measuring range began to appear in physiological, biological and medical laboratories. Experimental data of great diversity began to accumulate.

This can be considered the end of the prehistory of the use of electricity in medicine and of the study of “animal” electricity.

The historical stage in the scientific-technological and medical-biological use of electricity has been marked by the development of new physical techniques providing primary biological information, the development of electrical measuring technology, the information theory, autometry and telemetry and the integration of measurements.

CHAPTER FIVE

The Physician's Electric Assistant

1. THE ORIGIN OF BIOLOGICAL CURRENTS

Electrography is the science of the connection between electrophysiological and clinical-anatomical processes in the living body. Electrography is the study of the electrical activity of living tissue, and electrocardiography is a diagnostic method of assessing the condition of the heart muscle and cardiovascular system by temporal variations in their electrical activity.

The use of electrocardiography began at the end of the 'twenties of the present century when the outstanding English electrophysiologist, Adrian, suggested employing the magnetic oscillograph for recording the electrical activity of the heart muscle, organs, nerves, etc. With this instrument electrical activity could be interpolated, and the curve recorded on paper tape. Electrical diagnosis began rapidly to develop. Making instruments intended for diagnosis became an independent branch of medical instrument manufacture. The development of electrical measuring technology and methods of recording, along with ever-increasing clinical experience, brought it about that the electrocardiograph, an instrument for recording the curve of cardiac activity, was soon to be found in every polyclinic, and today is one of the basic instruments for emergency medical services.

Many score years passed after the first observations of the electrical properties of living tissue before the electrocardio-

graph came into general use. Electrical measuring technology developed quite rapidly, and the electrical activity of the heart could have been measured sooner with the means available. This was not done because the nature of the phenomena associated with the heart's electrical activity was not clear. Solving this question required integrated physico-chemical and quantum-mechanical measuring apparatus.

It would be well to consider briefly existing explanations of the electrical activity of living tissue. Some of them appeared a long time ago. According to one of these explanations, electrical charges are formed at cell boundaries due to the transfer of matter. Their presence was demonstrated by a very crude experiment: between two electrodes mounted in a biological fluid containing live cells were placed two nonpolarizing (inert) electrodes, for example, platinum electrodes, and potential cut in. The cells became charge-carriers of a sort. Under certain conditions it was possible to determine the charge and the speed of migration.

A more widely accepted hypothesis was that potential originated as a result of the diffusion of ions as takes place in solutions of low concentration. In 1889 Walther Nernst, German physicist and chemist, proposed an equation based on experimental data and some reasoning, making it possible to determine the potential between two liquids of different concentration on coming into contact. Ions from the solution of higher concentration diffuse (migrate) into the solution of lower concentration. The difference in the mobility of the ions causes the appearance of a potential between two parts of the solution. But do diffusion potentials play a part in the formation of bioelectric potentials in biological systems? Probably not. The distance between moving charge carriers in biological tissue is very small, and diffusion quickly equalizes the concentration and the composition of the solution.

A membrane hypothesis was proposed, according to which there is a semipermeable membrane between individual constituents of a biologically active fluid which permits the pas-

sage of certain ions but holds back others. As proof of this hypothesis an experiment was cited in which a solution of albumen was separated from a salt solution by a cellophane membrane. The potential which arose, called the membrane potential, persisted even after general equilibrium had set in.

Developing this hypothesis, Academician P. P. Lazarev in the 'thirties, formulated a theory of excitation, advanced for its time, based on changes in the movement of charge-carrying ions. According to Lazarev's theory excitation of tissue sets in at a certain concentration of free ions. This theory made it possible to establish a general law of excitation and inhibition which also applied to the central nervous system. Attempts were made to explain by means of the membrane hypothesis not only the origin of bioelectric potentials, but also basic physiological phenomena. For a long time the membrane theory gave rise to no doubts. During the 'seventies it acquired new content. A new science appeared—membranology—although contradictions in explanation of the nature of bioelectric potentials were not completely eliminated.

In 1939 American scientists published a report of their observations of potentials arising between the external membrane and the internal contents of a primary nerve fibre. According to their findings the potential reached 40-50 mV. Higher potentials, up to 70-80 mV, have been observed by other researchers. On stimulation of the fibre the sign of the potential difference changes as do the values of the potentials. These facts are at variance with the membrane theory.

Academician D. N. Nasonov proposed the "phase" hypothesis of the origin of bioelectric potentials. According to this hypothesis, bioelectric potentials are associated with the distribution coefficient in a fluid of immiscible constituents, such as water and oil. The phase hypothesis explains a number of phenomena but it is out of line with the membrane theory and vice versa.

In 1942 J. Weiss discovered the transition of electrons from one molecule to another, which he termed the transfer of charge-

es. This most important discovery, which is in full agreement with modern conceptions of processes within compound semiconductors, is apparently the basis for revealing the nature of the origin of bioelectric potentials. Moreover, this means, as a matter of fact, that molecules and atoms are not independent, isolated elementary particles—the electron clouds of two molecules can overlap, and an electron of one molecule can use the orbit of another molecule.

The American physicist, Robert Millikan, formulated a quantum-mechanical theory of charge transport, systematizing available experimental data. This theory, as well as the rapid development of the science of the semiconductor properties of matter, including biological polymers, hold out great and most interesting prospects for study of the nature of bioelectric potentials. Probably there is a superposition of different hypotheses. Perhaps an entirely new explanation of the diversity of biological activity phenomena will be found. For the time being, practical electrography is based on a vast amount of empirical data and numberless clinical observations, and is effectively assisting the physician, which is all to the good.

2. THE ELECTROCARDIOGRAM

The electrocardiogram (ECG) is a curve of the temporal changes in the electrical activity of the heart, characterizing the work of the heart muscle during the period from the entry of blood into the auricles to its expulsion into the aorta and pulmonary-artery. In the diagram, potentials in millivolts are shown vertically, and time in seconds is shown horizontally. In order to obtain an ECG one has only to place on a person's body two electrodes with surface areas of 40-60 cm² and connect them to a measuring-recording instrument. Numerous investigations have revealed the regions of the body from which measurements give curves providing the most full information. The present electrocardiograph models

could supply fuller information if the range of recorded frequencies were extended.

In the preceding section it was related how much that is unclear and contradictory still remains in the basic conceptions regarding the origin of electrical activity. Yet these conceptions are advanced and evidence is cited in their favour. But in what way does electrical activity spread over the body, and why is it that when the electrodes are placed on some parts of the body, one curve is recorded, but when placed on other parts of the body, a different curve results—so far there is no convincing answer to these questions. General views regarding the electrophysics of the phenomena are extremely contradictory. Like the biophysics of the source of electric energy, determination of the ways in which bioelectrical currents spread over the human body require comprehensive investigations. Tribute must be paid to the electrophysiologists Yu. Yu. Chagovets, A. F. Samoilov, S. S. Steriopulo, V. F. Chagovets and E. Adrian, as well as the great army of Soviet and foreign clinical physicians who have been able to employ this most complicated phenomenon for the good of man. An applied science—electrocardiography—has sprung up. Electrocardiographic findings supplement the clinical picture of the course of a disease and assist the physician make the correct diagnosis and correctly assess the course of treatment. There is good reason for emphasizing that cardiographic findings supplement the clinical diagnosis, although in the overwhelming number of diseases they are equivalent. But although rarely, it sometimes happens that the clinical picture of the disease is not reflected in the ECG. Fig. 9 shows the ECG of a healthy person. It consists of three upward waves, *R*, *T* and *P*, and two downward, negative waves, *Q* and *S*.

The beginning of the cycle at the *P* wave indicates the beginning of the work of both auricles which finishes with the *Q* wave. The *P* wave appears when excitation of the auricles sets in. The left half of the *P* wave to amplitude corresponds to the work of the right auricle receiving venous blood; the

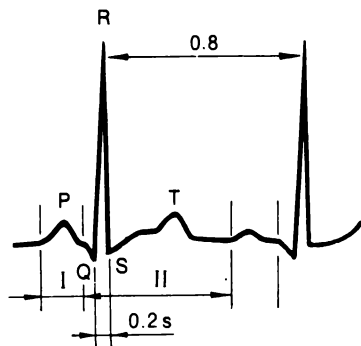


Fig. 9. Normal electrocardiogram of healthy person

I—Interval of work of auricles, characterized by *P* wave; *II*—*QRST* interval—work of ventricles

right half of the *P* wave, the work of the left auricle receiving blood from the lungs. The entire *QRST* complex characterizes the work of the ventricles: from the left, blood passing through the aorta enters the vessels to supply oxygen to the body tissues; from the right, blood passes to the lungs for enrichment with oxygen. The potential amplitudes of the waves and the intervals between them provide information about the condition of the heart. Ranges: for *R* wave, from 0.3 to 0.4 mV (normal); for *P* wave, hundredths of a millivolt.

Maintenance of the shape, phases and amplitudes of the curve of electrical activity indicates normal, resolute work of the heart. Deviations from the normal ECG—changes in the time intervals of the entire cycle or between all or individual phases, changes in the potential amplitudes of the waves, or changes in their sign, as sometimes occurs in the *T* wave, and a change in the correlation between potential values—indicate an impairment of cardiac activity. One of the indications of serious impairment is a break in the curve or a marked

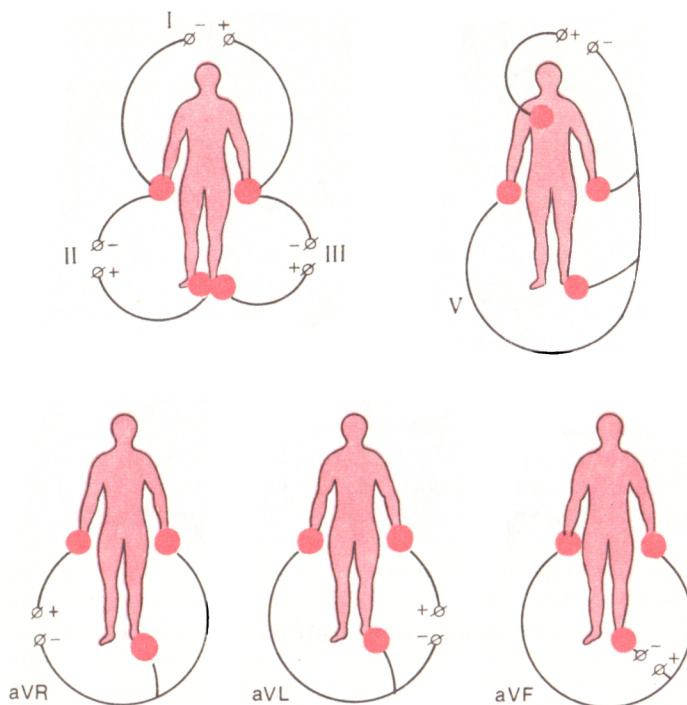


Fig. 10. Typical leads for taking electrocardiogram (explanation in text)

change in its shape, for example, a curve is rounded instead of being sharply pointed. The changes mentioned are not exhaustive. They are observed both in the classic, first lead (lead I in Fig. 10), and in others. Fig. 10 shows the arrangement of the different leads, and Table 1 gives their designations. Fig. 11 shows the most typical changes in the ECG, characterizing



Fig. 11. Electrocardiograms in different diseases of the heart

different forms of heart disease. These changes along with other symptoms, such as abnormal arterial pressure, and indicators associated with biochemistry, enable the physician quickly to make a diagnosis and take necessary measures in good time.

Thus without knowing everything about the source of electrical activity, and the nature and fundamental principles of the spread of bioelectric currents through the body, man ably uses electricity, something that is inherent in him, in his life, with the object of preserving his health. The reader will learn in the next section how electrical activity is measured and how the ECG curve is traced.

3. THE ELECTROCARDIOGRAPH

The electrocardiograph is an instrument designed for measuring the potential characterizing the work of the heart muscle over a range of 0.01 to 0.50 mV and recording the result on paper or photographic tape, or on the screen of an electronic oscillograph. The instrument's input system has an active resistance ranging from 0.5 to 2.0 Mohm, so it would be more correct to speak of the electric activity of the heart muscle as "tension," rather than "bioelectric potential". The electrical activity of the heart muscle can be characterized by the value of the energy generated. If the potential of the *R* wave on the ECG, which comes to 0.3-0.5 mV, is divided by the input resistance of the electrocardiograph (500 kohm to 2 Mohm), it gives a current of approximately 10^{-11} - 10^{-12} ampere. Knowing the current and the potential, it is possible to calculate the electric energy developed during the work of the heart for any period of time. It is possible that in the future this value can be used as a diagnostic characteristic.

The electrocardiograph consists of the following basic units: electrodes placed on the patient's body; a fast amplifier making it possible to obtain an electrocardiographic signal which can directly activate an electromagnetic measuring instrument with potential recorder; a tape-moving mechanism; a standard source of potential, for checking the scale of measured potentials; a set of cords for connecting the electrodes to the electrocardiograph. For recording the curve from the moving system of the electromagnetic instrument, ink is fed to the paper under slight pressure. Ink recording provides an ECG curve with less distortion but operation is more complicated.

The ECG curve varies, depending on the part of the body from which it is taken. The principal elements of the curve are retained but the shape and amplitudes differ. Explanations of this phenomenon in classic works on electrocardiography differ. At times it is said that since the electrodes are positioned differently in relation to the source of current,

the resistance between the electrodes and the source differs. Some investigators assert that it is due to the local distribution of electrical activity on the surface of the heart muscle. When the nature of the generation of electrical energy by the living body is revealed, a convincing explanation will be found for the different forms of the ECG curve taken from different parts of the body. Today the physician's experience shows that curves obtained from different parts of the body provide information extremely useful for diagnosing diseases of the heart. The leads most often used are shown in Table 1.

Besides these basic leads, chest leads are used for a complete electrocardiographic examination. In this case the electrodes are placed on the surface of the chest at the right edge of the sternum, at the left edge, on the left axillary line and a number of intermediate points.

Table 1

Typical Electrocardiograph Leads

Designation	Positions of electrodes	
Standard I (classic) II III	Left arm Left leg Left leg	Right arm Right arm Left arm
Augmented aVR aVL aVF	Right arm Left arm Left foot	Left arm with left foot Left foot with right arm Right arm with left arm
Chest $V(V_1 - V_6)$ CR CL CF	Chest (six positions) Chest Chest Chest	Right arm with left arm and left foot Right arm Left arm Left foot

English letter symbols: a — augmented; C — chest; F — foot; L — left; R — right; V — volt (potential)

Electrocardiographs are classed as single-channel, double-channel and four-channel. Leads are switched on and off with switches mounted in the electrocardiograph. This makes it unnecessary to move the electrodes placed on the extremities. For convenience in selecting the desired wire to be connected to the electrocardiograph the wires or plugs have coloured markings, say red for the right arm; yellow, the left arm; green, the left foot, etc. To give a good contact and reduce the resistance between the electrode and the skin, a piece of cloth moistened with saline is placed under the electrode or the skin is rubbed with conducting paste. Electrodes on the extremities are secured with rubber bands. Electrodes on the chest are secured with suction disks or a special flexible strap. The cardiograph most widely used in the Soviet Union is the type 060 or 061 portable single-channel direct-reading instrument (Fig. 12). It is intended for use in out-patient clinics and polyclinics and at the patient's home. Since this is a pen-recording instrument, the ECG curve is immediately visible. The pen moves in an arc, so the grid on the paper tape for recording the curve is in the form of a radial system of coordinates with a radius equal to the length of the pen.

Operation of the electrocardiograph is as follows. Electrodes are placed on the patient's body and connected by flexible wires through the lead switch to the input terminals of the amplifier. The amplified bioelectric potential is fed to the moving coil of a recording electromagnetic voltmeter. When the circuit is set up, the nurse pushes the check button and feeds a potential impulse to the instrument from the standard source. The height of the rectangular impulse corresponds to one millivolt and is used for determining the amplitudes of all the impulses in the electrocardiogram. The length of the paper tape for the recording from all the leads comes to 1-1.5 m; in the double-channel instrument it is correspondingly less. The advantage of the double-channel instrument is that it is possible immediately to compare curves from two different leads. This advantage is particularly important in the clinic,

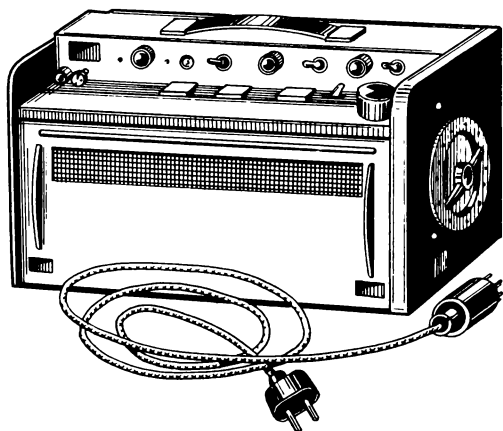


Fig. 12. Single-channel electrocardiograph

but in general medical practice the single-channel instrument has fully proved its worth.

The Krasnogvardeets firm has developed two new electrocardiograph models—"Salyut" and "Malysh". They are of lighter weight and have a more reliable recording system. The use of semiconductors makes them more reliable in operation. Undoubtedly they will be well received by physicians.

4. REMOTE DIAGNOSIS

So the value of the potential induced during vital activity and its temporal changes characterize the body's condition. The use of the electrocardiogram in determining disorders of the cardiovascular system and the myocardium is an example showing what a valuable assistant the physician has in "animal electricity". It is also a trusty assistant in diagnosing many other diseases. Modern electric measuring technology has

made it possible to record quite simply impulses, time intervals and the shape of impulses of "animal electricity".

But the opportunities provided the physician by radio electronics and radio engineering are immeasurable! The physician examines a patient and listens to the tones of his heart while the patient is lying in bed or standing before him. But the heart often aches when a person is walking, doing physical work or other work and not when he is at rest. The local physician is now limited in his information about a patient's condition to what is ascertained when the patient is at rest. Radio electronics and radio technology provide the physician with a fundamentally new method of diagnosis.

At the end of the 'twenties I. P. Pavlov timidly expressed the desire for measuring apparatus to be designed making it possible to observe from a distance the condition of a test animal or a man at work. At the beginning of the 'thirties he was more insistent in his request. Pavlov's pupil, co-worker and friend, L. A. Orbeli, an outstanding physiologist, set about realizing this idea.

Orbeli together with A. A. Yushenko and L. A. Chernovkin designed a transmitter to be mounted on the animal's back. Using this transmitter and a receiving device they also designed, the dog's behavior could be recorded at a distance. Thus, the test animal, the "radiofied" dog, was not limited in its movements. Such an experiment was a major and fundamentally new advance.

The primitive radio apparatus of that period was too large and heavy. There was, as yet, no thought of microminiaturization.

In the postwar years, and especially in the mid 'fifties, there was extensive designing of measuring devices to be mounted directly on test animals under observation. In 1963 a radio transmitter incorporating five transistors was designed. Together with the power source, a mercury-oxide battery, it weighed only 36 grams. It was 7.6 cm long and 3.5 cm in diameter. The transmitter could operate 20h with a range of about

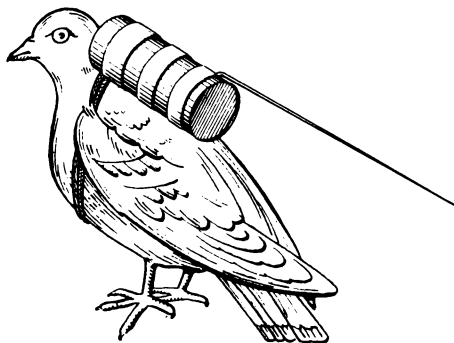


Fig. 13. Radio transmitter on pigeon for telemetry of pulse

one km. The first discovery was astonishing: when such a transmitter was mounted on a pigeon to transmit the pulse rate according to the number of maximum amplitudes in the ECG, it was found that when the pigeon was at rest the pulse rate was 150-170 per min, and in flight, 350-600, i.e., an almost threefold increase. Fig. 13 shows the pigeon with transmitter mounted.

In the mid 'fifties, systems were designed for transmitting the pulse rate in parachutists at the moment of their jump, according to the number of maximum amplitudes in the ECG. And not only the pulse rate was transmitted but the entire ECG. Soon these radiotelemetering techniques, i.e., the transmission of measured values to a distance by means of radio, began to be used when training aircraft crews.

On April 12, 1961, the first spaceship was launched, piloted by Yuri Gagarin, and on August 6, the same year, the second spaceship, Vostok-2, was put into orbit, this time piloted by G. S. Titov. During these flights there was continuous monitoring of the astronauts' cardiac activity, the electrocardiogram being transmitted to earth and used for counting the pulse. There was simultaneous monitoring of the respiration and

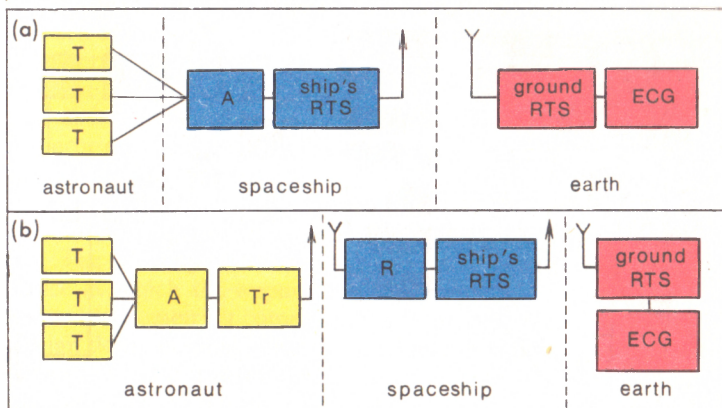


Fig. 14. Diagram of transmission of information characterizing the astronaut's condition: *a* — direct transmission of information to earth; *b* — transmission of information with relaying

T — transducer; *A* — amplifier; *Tr* — transmitter; *R* — receiver;
RTS — radiotelemetric station; *ECG* — electrocardiograph

other functions of vital activity by means of transducing systems and radiotelemetry. The diagram in Fig. 14 shows how information characterizing the astronaut's condition was transmitted. It can be seen from the diagram that the signals for the ECG are transmitted to earth and the ECG recorded there. The potential generated by the heart muscle is fed from electrodes on the body to an amplifier and then to the ship's radio transmitting system. A version of the transmitting system with relaying of the signal is also possible. This is preferred by astronauts and fliers since the entire system is on them, and there is no bundle of wires stretching from them. Fig. 15 shows the system for transmitting information from the flier by biotelemetry. The version of the transmission system without an intermediate radio receiving system (it can be called the space system) has found application in medicine for studying the

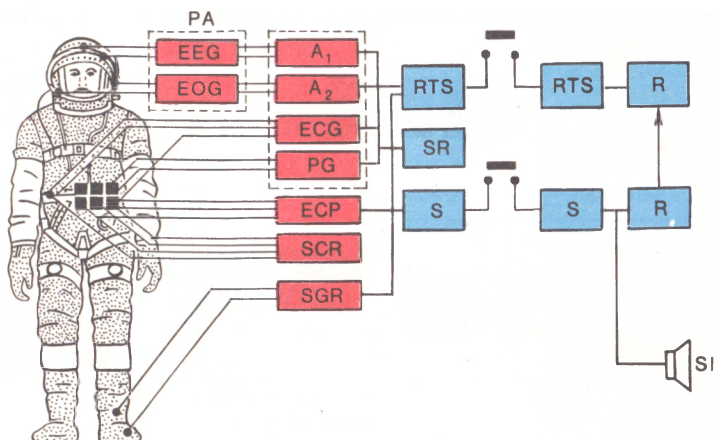


Fig. 15. Diagram of information-taking layout in biotelemetry

PA – preamplifiers (*EEG* – electroencephalographic, *EOG* – electrooculographic)
*A*₁ – *EEG* amplifier; *A*₂ – *EOG* amplifier; *ECG* – electrocardiographic amplifier;
PG – pneumographic amplifier; *ECP* – electrocardiophonic amplifier; *SCR* –
 self-contained recorder; *SGR* – skin-galvanic reaction amplifier; *RTS* – radiotele-
 metric system; *SR* – ship's recorder; *S* – “Signal” transmitter and receiver;
R – recording device; *SI* – sound indicator

physiology of work and sport. Great services in the develop-
 ment of Soviet radio-biotelemetry have been rendered by
 A. I. Berg, V. V. Parin, E. B. Babsky and A. A. Zlatorunsky,
 et al.

V. V. Rozenblat and the laboratory he heads in Sverdlovsk
 were pioneers in the use of biotelemetry for assessing a per-
 son's working capacity. The telemetry laboratory organized
 at the initiative of A. V. Deryabin was the base for introduc-
 ing biotelemetry into health resort practice. At time of writ-
 ing biotelemetric systems are being organized at various med-
 ical institutions, sanatoriums and industrial enterprises.

To the credit of the All-Union Scientific Research Institute, "Electronstandart", is its initiative in designing, jointly with the Leningrad Institute of Aircraft Instrument Manufacture and the Kislovodsk Telemetric Laboratory, telemetric apparatus and launching its serial production for extensive use at sanatoriums and health organizations.

Present-day biotelemetric apparatus consists of a system of transducers secured to the examinee's body with adhesive plaster, and a system of wires for connecting to the radiotransmitter. The capacity of the radio transmitter depends on the distance at which the apparatus should operate; for short-distance biotelemetry it comes to 20 mW or less. When observing a man doing manual work or an athlete in action in a gymnasium, the radio transmitter has a capacity of 100-200 mW and the radius of operation is increased to 5-8 km. The frequencies adopted for the transmission of biological information have been set at 45 and 140 megahertz. The signal transmitting system, the modulation, is of the frequency type. A compact transmitter is similar in size to a usual transistor with the same aerial. At times the aerial is mounted in the hat. The signal characterizing cardiac activity is amplified in the receiver and fed to the standard electrocardiograph or other instrument which records processes on paper or photographic tape. Many difficulties were encountered when selecting places for mounting the electrodes, since the positions mentioned in the preceding section for the usual ECG were found to be unsuitable. Excessive interference due to various causes made it difficult to decipher the transmitted signal. Chest positions arranged vertically were found to be optimal.

Using this apparatus for monitoring a person's condition without direct contact with the physician, the ECG was obtained, which enabled assessment of cardiac activity as well as determination of the pulse rate; respiration characteristics—rate and depth—were also obtained. In the case of respiration there are as yet no adequate transducers of primary information. The most reliable is one comprising a va-

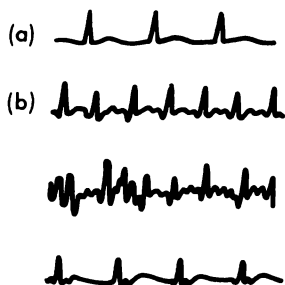


Fig. 16. Radiotelemetric electrocardiogram while subject is doing physical work: *a*—when beginning work; *b*—at different stages of the work

riable resistor which changes during breathing. The change in resistance is then transduced into an electric signal. The amplitude of the signal indicates the depth of breathing. The number of signals per minute is the respiration rate. Transmitting the body temperature is not difficult. There are prospects in the immediate future of transmitting energy consumption when performing work of one kind or another. Experiments carried out at the Leningrad Institute of Aircraft Instrument Manufacture have shown that energy consumption in an athlete in action, as determined by the heat exchange or the inspired-expired oxygen quotient, varies, depending on whether or not he is trained.

The most important and fundamental achievement in biotelemetry is the establishment of the fact that the shape of the ECG curve characterizing cardiac activity is the same in a healthy person at rest and during lengthy activity. Furthermore, it has now unquestionably become possible to assess the work of the heart under different loads. Fig. 16 shows the electrocardiograms of a person doing physical work—when beginning work and at different stages of the work.

As a whole, biotelemetry is at the beginning stage of its de-

velopment. Much will be improved and ways of doing this are already being marked out. For example, it would be advisable to combine transmission of biological information with two-way radio-telephone communication. The number of types of information will of course be increased.

One of the fundamentally new forms of information is information for diagnosing gastro-intestinal disturbances.

Existing methods for diagnosing gastro-intestinal diseases are complicated and in a number of cases inadequate. Procedures also involve unpleasant sensations for the examinee due to the necessity of swallowing a gastric tube. Some regions of the gut are inaccessible without surgery. It is likewise practically impossible to measure the temperature of the stomach and intestine, or the pressure within them.

These difficulties are overcome by new diagnostic techniques employing a miniature transmitter with transistorized generator of high-frequency radio waves, and a system of transducers for converting temperature, pressure and acidity into electric signals. The transmitter, generator and transducer are contained in a capsule.

The appearance of the radio capsule is shown in Fig. 17. It is easily swallowed by the patient, and as it passes through the gastro-intestinal tract, the generator transmits signals, the values of which depend on changes in the value of the characteristic being investigated. The signals from the capsule are received by an aerial mounted on the patient or beside him. The aerial is connected to a receiver in which the signals are amplified, automatically deciphered and recorded on paper tape.

The curves obtained enable the physician to evaluate the temperature along the entire gastro-intestinal tract, pressure and acidity. The capsule passes through the gastro-intestinal tract in the space of several hours and is naturally discharged from the body. Its use has no effect on the examinee's health. Specifications of the radio capsule: length, 20-24 mm; diameter, 6-8 mm; weight, 2-3 g; continuous service life, 72 h. The

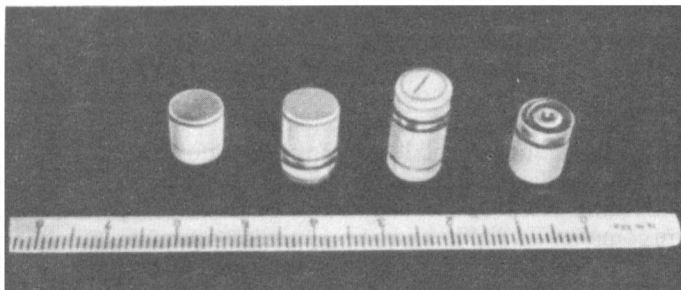


Fig. 17. Radio capsules

receiving device is operated from 220 V mains, and is no larger in size than a modern TV set.

Prof. E. B. Babsky is one of the initiators in introducing this diagnostic technique. Undoubtedly this method will in the near future substantially increase the possibility of obtaining biochemical and other information on a person's condition directly from the body.

The rapid development of biotelemetry in various fields of medicine, physiology and sport is primarily associated with the development of aviation and especially with space flights since such flights are impossible without medical monitoring of the crews of the piloted space ships.

5. TAKING MEDICINE WITHOUT POWDERS OR PILLS

The reader is already prepared for this section. It was mentioned in the preceding chapter that one of the first applications of electricity in medicine was the use of electrolysis for administering medicine through the skin. The discussion of ionic conduction will also be recalled. The particular feature

of this form of conduction is the transfer of matter. The atom or molecule has either a superfluous electron or lacks an electron. When potential is applied to the solution, the negatively charged ions (anions) begin to migrate through the patient's body to the anode, electrode connected to the positive source of potential, while the positively charged ions (cations) move to the cathode, the negative electrode.

To transfer one gram-equivalent of substance in solution (the gram-equivalent of a substance is its chemical equivalent expressed in grams, i.e., the ratio of the atomic mass to the valence) always requires the same amount of electricity—about 100,000 coulombs. The electrolytic method of transferring matter is employed in one of the oldest means of treatment—electrophoresis or ionophoresis. The ionic and combined conductivity of biological tissue, although it corresponds to Faraday's general laws, is considerably more complicated. But here, too, the experience gained in the administration of drugs by electrophoresis over scores of years has been of assistance.

In the first method of electrophoresis, the drug is administered through the hand or foot (Fig. 18). In this case the hand or foot is immersed in a bath containing a solution of the drug. One of the electrodes is placed in the bath and the other is secured on the extremity above the place where the hand or foot is immersed in the bath. In this form of electrophoresis, carbon electrodes are usually employed, since in that case there is a minimum of contamination of the bath during passage of the current due to impurities in the electrodes.

The second method of electrophoresis is more widespread. Both electrodes, which are in the form of flexible metal plates are secured to the patient's body above a layer of flannel, unbleached calico that has been defatted by boiling, gauze or at times simply filter paper. The material between the electrodes and the patient's body is impregnated with the drug. When the electrodes are secured in place the current is turned on, and electrophoresis begins. The electrodes can be of pla-

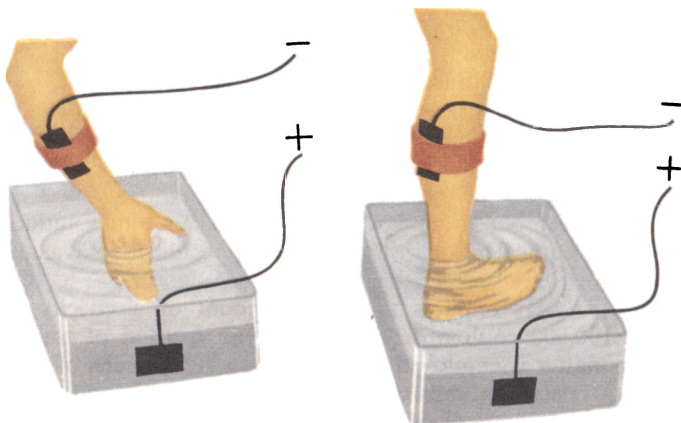


Fig. 18. Electrophoresis of drugs, using baths with carbon electrodes

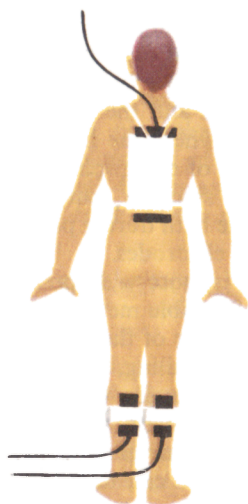


Fig. 19. Electrophoresis using applied electrodes

tinum, gold, silver, brass, aluminium or lead—a metal to which the drug must be inert. The most frequently used metal is sheet lead, which is sometimes covered with a thin layer of tin. Sheet lead is convenient in that it can be bent to fit any part of the patient's body, and easily cut to any shape with scissors. The area of the electrode depends on the therapeutic needs as set by the physician and ranges from 15-20 to 200-300 cm² (Fig. 19). The electrode is 0.5-1.0 mm thick and must be free from sharp angles, burrs and dents, otherwise the current density will not be uniform, which in some cases may even be dangerous. The optimal current density is established by experiment, and ranges from 0.03 to 1 mA/cm². If the surface area of the anode and cathode differ, the current density is set by the smaller electrode. The current strength in the circuit as a whole is also limited and must not exceed 40-50 mA. When the electrodes have a large surface area the currents may be considerably smaller. The potential used in electrophoresis is 15-20 V. Patients are given up to 15 treatments of one to 15 min each.

Electrophoresis is used for administering antibiotics, iodine-containing drugs and complex compounds. The action of drugs is manifested differently than when the same drugs are administered by other methods (pills or mixtures *per os*, or intramuscular and intravenous injections). Drugs administered by means of direct current have a general action on the entire body. Drugs accumulating in the skin irritate the nerve endings. They are irritated directly by the chemical compounds administered and by the electric current. Apparently there is an alteration of electric conduction under the action of the current. At the same time the drugs are absorbed into the capillaries with the stream of blood and lymph and are carried by these systems to all parts of the body, acting upon the tissues that are most sensitive to the given substance. Thus the general action of a drug administered by electrophoresis is made up of reflex and humoral effects. By selecting suitable drugs and an appropriate current schedule, it is possible to obtain a pre-



Fig. 20. Diagram of experiment illustrating the significance of electrode polarity (with the polarity shown in the picture, the rabbit on the left will be killed)

dominantly reflex or humoral action. The drug penetrates into living tissue to a depth of 1-1.5 cm.

Very interesting conclusions can be drawn from the work of N. D. Troitskaya on the action of current on the skin. Her test animals were guinea pigs, animals whose skin is similar in structure to that of man. Electrophoresis on a dead animal proceeds like the usual electrolysis of a complex compound, and even the depth of penetration can be calculated. Electrophoresis on a living animal is accompanied by most complicated reactions of the entire organism. In this connection it should be emphasized once more that in the living animal there is a more complicated alteration of electric characteristics. For that reason the action of a drug introduced through the leg is manifested in all parts of the body, while its action on a dead animal can only be detected in a small area under the electrode since further away the density of the current diminishes and its manifestation is practically imperceptible.

The polarity of current is of great importance. A. P. Parfenov cites an interesting example of the action of current of different polarity. Conducting pads moistened with solutions of strychnine and sodium chloride were secured on the sides of two rabbits. In one rabbit the pad moistened with strychnine

was on the right side and in the other rabbit the strychnine was on the left. The two rabbits were connected in series in a common circuit. In one rabbit the pad moistened with strychnine was connected to the positive pole of the power source; in the other rabbit the strychnine pad was connected to the negative pole. The moment the circuit was closed one rabbit died—the one in which the pad moistened with strychnine was connected to the positive pole. When the polarity in the circuit was changed, the other rabbit died. A diagram of the experiment is shown in Fig. 20.

Only two examples of the use of electricity, inherent in the living organism, as the physician's assistant have been cited in this section: in making a diagnosis (an examinee's condition is assessed by changes in the electrical activity of the heart muscle) and as direct treatment, the effect of which is due to the interaction of the external electric current and field with the electric currents and fields inherent in the living organism.

Considerably more examples could be cited. Investigations along this line are continuing.

Part Two

ELECTRICITY IS DANGEROUS

CHAPTER SIX

In What Way is Electricity Dangerous?

1. EVENTS IN VASILEVSKY ISLAND, ST. PETERSBURG

In the middle of the 18th century two events occurred which have a direct bearing on the subject of this book. In England, at a session of the Royal Society, Collinson, one of the members, read out some letters he had received from his friend, Benjamin Franklin, the American scientist, telling about his observations during a thunderstorm and his assumption that lightning was similar to the discharges on electrophore (electrostatic) machines. Lomonosov considered this report an event of the greatest importance in the development of science. Lomonosov and Rikhmann, who were engaged in systematic observations, had long been interested in atmospheric phenomena taking place during thunderstorms. One of the interesting instruments in Rikhmann's laboratory in Vasilevsky Island, Saint Petersburg, was an electrostatic machine and a sort of voltmeter he had made. Rikhmann and Lomonosov had before this observed the phenomena described in Franklin's letter. Lomonosov's great service to science was that on the basis of a great number of laboratory experiments and observations of atmospheric phenomena he formulated

the first well-grounded hypothesis regarding the nature of atmospheric electricity. He had come to the conclusion that atmospheric electricity appeared during the movement of masses of air and the accumulation of carriers of electricity formed by the friction of the masses of air. Developing this interesting hypothesis, Lomonosov demonstrated the presence of electric charges in the air when there was no sign of a thunderstorm. Thus the first event was the discovery that electrostatic and atmospheric electricity are the same in nature.

The second event was tragic — Rikhsman's death from a stroke of lightning. This tragedy is well known, and everything connected with it is told in A. Morozov's book, "Lomonosov", published in Moscow in 1965, so we will only cite some excerpts from Lomonosov's letter announcing Rikhsman's death, concerning the way in which a person can be killed by lightning. The entire letter can be found in Morozov's book.

"Dear Sir! (The letter was to Count I. I. Shuvalov who was in authority over the Academy of Sciences. *V. M.*). That I write to you today is a wonder because dead people do not write. I do not know yet or at least wonder whether I am alive or dead. I see that Professor Rikhsman has been killed by lightning in exactly the same circumstances in which I was and at the same time. On the 26th of July at one o'clock in the afternoon a great cloud rose in the North. The thunder was very strong but there was not a drop of rain. I looked at the lightning machine which had been set out (Lomonosov is speaking of a lightning conductor in the form of a metal bar on the roof of the house. *V. M.*) but could not see the slightest sign of electric force. But while food was being put on the table I waited, expecting to see electric sparks on the wire, and at that time my wife and the others came, and like me they kept touching the wire and the suspended bar, because I wanted witnesses of the different colours of the fire about which the late Professor Rikhsman had argued with me. I had only been sitting at the table a few moments when sudden-

ly the late Rikhhmann's servant opened the door, all in tears and out of breath with fright. I thought someone had beaten him on the way when he was sent to me, but he gasped: "Professor's been hit by lightning!" The first stroke from the rod hung with a thread (part of the instrument for measuring atmospheric electricity. *V. M.*) struck him in the head. There was a bright red spot on his forehead and the electric force of the lightning went out through his feet into the boards. His feet and toes were blue and his boot was torn but not burned". The letter ends with a description of the measures taken in an attempt to revive Rikhhmann. Lomonosov speaks highly of Rikhhmann as a scientist and man, and requests that his family should be given assistance—a request that shows Lomonosov to have been very kind-hearted.

From these excerpts it is evident that Lomonosov called attention to the fact that under the same or very similar conditions one person was struck and killed by lightning but another was unharmed. He also noted that everything indicated that death had been instantaneous.

In the 'twenties of this century the Austrian scientist Jellinek, referred to in Chapter Two, asserted on the basis of observations carried out in different conditions that death from electric shock could be instantaneous and without any visible signs of injury.

In the first half of the 19th century, the Russian physicist, Academician V. V. Petrov, noted the particular features of injury and death from electric shock.

Having carried out investigations with a unique electrochemical source of current developing a potential up to 2000 V, Petrov established the fact that contact with such a potential was dangerous and could result in serious consequences, and that the action was different for different species of animals. He also pointed out how serious consequences could be avoided. It is interesting to note that Petrov asserted that shock from such a source was similar to the stroke of lightning that had killed Rikhhmann.

2. ELECTRIC TRAUMA AND SOME STATISTICS

The first description of death from man-made electricity, rather than from lightning, appeared in the middle of the 19th century. In this fatal accident the victim had come into contact with the live part of an electric installation. This description was followed by others. Somewhat later these reports began to be systematized with the object of working out effective safety measures. In 1880 the magazine *Elektrichestvo*, and in 1898 the magazine, *Elektrotekhnika*, began systematically to publish descriptions of injuries and deaths from electric current, as well as the first statistics which were necessary for preventing such accidents as far as possible. By this time it had been more or less firmly established that electric current could kill a person and an electric arc could cause such serious burns that a person might not recover. Finally, numerous observations showed that electric shock from accidentally touching a live wire or other conductor was a sudden irritating action not usually followed by any perceptible consequences, but sometimes leaving signs of injury, or electric trauma, as it is now called.

An electric trauma should be understood as impairment of the anatomical relationships and functions of tissues and organs, accompanied by a local and general reaction of the body. Electric traumas are classified as follows: traumas associated with disturbances of the normal operation of electric installations in which a circuit is formed through a person's body, and traumas in which no circuit is formed through a person's body. In the latter case injury may be in the form of burns or blinding from an electric arc, falling which may result in serious fractures. The latter group includes mixed traumas in which the victim suffers both types of injury. This classification makes it possible during the recording and processing of statistical data to reveal more effectively the possible danger spots and causes of injury to people by electric current, and also to disclose electric traumatism.

Electric traumatism is to be understood as the origin and recurrence of electric trauma in certain groups of the population in similar occupational, domestic, sport and other conditions and circumstances.* How do matters stand in regard to electric traumatism?

Ever increasing number of people are having something to do with electric apparatus, instruments, appliances and installations in industry, transport, municipal services and everyday life. Electric energy consumption in the Soviet Union is increasing by 6–8% annually. In 1971 it came to 800 thousand million kilowatt hours. In the tenth and subsequent five-year periods the increase will be still greater.

In the USSR great attention is being devoted to safety engineering which is seen in the daily monitoring of electric installations to ensure proper operation, and also in the introduction of accident-preventing means and measures. As a result the number of traumas per million of the population or per million kW h of energy consumed is falling.

Yet the absolute number of electric traumas is still high. In some sectors of the national economy it is decreasing, and there are enterprises where there has not been a single case of injury to a person from electricity since operation began. But at the same time there are individual enterprises and sectors of the national economy where the number of traumas with serious outcome is not declining, but even rising. This refers particularly to the municipal services. The number of traumas in everyday life has also increased.

The number of traumas in agriculture is also increasing, especially in dairying and animal husbandry. The industrialization and electrification of agriculture is being intensified. At the same time the operation of electric installations and power lines is becoming more efficient, and labour discipline

* Gordon, G. Yu. et al., *Proizvodstvennyy electrotravmatizm* (Industrial Electrotraumatism), Leningrad, 1971.

is improving. There are grounds for assuming that in agriculture too, electric traumas will begin to decrease.

When speaking of the incidence of electric trauma, the term "danger spot" is sometimes used, meaning a temporary or even constant situation in the operation of electric equipment or power lines in which like or similar cases of injury occur.

Here is an example. For a long time not enough attention was paid to the low quality of installation parts, such as starter covers and mounts, terminal boxes and switchboard bases. This led to a large number of serious injuries from electric shock. When the technical public, the management of enterprises and leaders of sectors of the national economy became uneasy and measures were taken to seriously improve the insulation of such parts, the number of accidents involving these parts sharply decreased. This was shown by an analysis of electric traumas carried out by the Leningrad Institute of Labour Protection.

But there is still much to be done to control electric traumatism, especially in agriculture and everyday life.

3. TEMPORARY WIRING

At industrial enterprises and construction projects it is often necessary to use temporary wiring to run an electric tool or portable machine, or for illumination. In everyday life temporary wiring is used when developing photographic film, and for connecting vacuum cleaners, washing machines and electric irons. Often in such cases the wire used is that intended for permanent mains and is not flexible. The installation parts are also intended for permanent use. Naturally the probability of insulation being damaged is greater in temporary wiring, causing many traumas, including traumas with serious consequences, as is shown by statistics.

An analysis of accidents indicates an increasing number of electric traumas in everyday life, but it should be noted that

there is a change in the nature of these accidents. At the beginning of the century electricity replaced kerosene and gas for illumination. At first the electric socket was usually mounted in a kerosene lamp in the place intended for the wick. The sockets and switches were of brass, and were insulated from the current-carrying parts by strips of cardboard bent into rings. The current-carrying parts themselves were mounted on porcelain or ceramic bases. The switch handles were metal. Such insulation of sockets and switches could be damaged by vibration of the building or as a result of inferior assembly so that people were often shocked, especially when changing bulbs.

In recent years two measures were carried out that were not noticed particularly by the general public but which were of considerable significance in the control of electric traumatism. Practically everywhere electric illumination has been changed from 220/127 V to 380/220 V. It would seem that with the increase in voltage there should be an increase in the number of accidents but that has not taken place because the shells of sockets and switches are now made of plastics. Unfortunately injuries are being caused by other defects in municipal and household mains and wiring.

In nonindustrial traumatology as a whole, including besides electric traumas, falling, burns, road accidents, etc., electric traumas, serious and not serious, comprise a small percentage, but when it comes to fatal injuries the percentage is high. Some authors consider that 10 to 15% of all fatal accidents are caused by electricity and cite figures to prove this. According to one foreign author, electric traumatism in capitalist countries is a national calamity. There are still many electric traumas in the Soviet Union. In order to stress the importance of safety measures to prevent accidents and ensure efficient operation of electric installations we end this paragraph with a general assessment of electricity victims the world over. There are no exact statistics but on the basis of surveys published in some countries, one draws the conclusion that 22-25 thousand people die from electric shock every year. Of course that figure

is many times smaller than the number of people killed in road accidents, but it is still large.

One must know of the dangers to man inherent in electricity. The rules and regulations for operating electric equipment and electric wiring must be observed. In general they are not complicated for the population, and if observed electricity will only serve people. Some of the ways and circumstances, at times absurd, in which electricity can cause injury are related in the following paragraphs.

4. A "HORSE ACCIDENT"

In Dickens one finds vivid descriptions of the roadways of London. For a long time such roadways were found in other capitals and large cities, including Leningrad. Long ago the roadways were simply planking, but in time this gave way to hexagonal, butt-end paving blocks. It was a roadway of this kind in what is now known as Lomonosov Square in Leningrad that figured in an incident in 1928 still called the "horse accident". In a small patch of greenery in the centre of the square was a cast-iron well housing an electric air-break switch. The well resembled a metal barrel and was earthed with two-metre pipes driven into the ground beside it. The porcelain insulator to which the switch was secured had broken and the switch was hanging on the wire but did not touch the body of the well, so there was no short-circuit. The switch inside the well remained under a tension of 2000 V. It began to rain and the roadway was wet. A heavily loaded wagon passed near the well and people were walking by. Under the weight of the wagon the roadway under the well sagged slightly but it was enough for the switch to come close to the side of the well and arc across in a short-circuit. This created a high ground potential gradient on the roadway and pavement near the well, and people nearby felt a shock. The horse was in better contact with the roadway because of its greater weight and iron shoes, and since the distance between its legs was greater was

killed outright. The short-circuit lasted only two seconds because the current was shut off by the automatic circuit-breaker at the electric station. In the square, the sudden death of the horse and the electric shock the people had felt caused great confusion, and a crowd gathered. Soon a patrol of mounted militiamen appeared.

At the electric station, the engineer on duty saw that a circuit-breaker had cut out one of the cables and tested the insulation with his instrument. He found everything in order because there was a gap between the switch and the side of the well. He therefore supposed that the circuit-breaker was at fault, and closed the circuit again as he was supposed to do according to the instructions then in force. When the current was turned on, the switch again arced across to the well, and again for only two seconds but that was enough to kill two more horses, and give the people in the square a bad shock. According to instructions, the engineer could not close the circuit-breaker a second time, so that was the end of the incident. Soon the iron wells—a left-over from pre-revolutionary engineering—were discarded and the roadway was paved with asphalt.

5. EXAMPLES OF ELECTRIC TRAUMA

One can learn more about cases of people and animals being killed by ground potential gradients from the literature. Usually this has taken place in the country when high-tension power lines have broken. One case is recorded in which several people were killed on the grounds of a substation. Fortunately such accidents are rare, but there is a conclusion that must be drawn from them: never go up to the wire of a transmission line lying on the ground, and never touch one under any circumstances. And this applies not only to high-tension transmission lines but to ordinary lighting wires.

In cities and suburbs 220 V aerial lines are being replaced

by cables. Break-downs are much more frequent in aerial lines and the accidents involved, even at this voltage, are incomparably more numerous than when cables are used, and accidents occur in situations that are difficult to imagine. Since there are still 220 V aerial transmission lines in a number of suburbs and some large cities, and they remain predominant in rural areas and settlements, we will describe an incident showing how important it is to observe the simple regulations for the operation of such circuits.

In a suburb of an industrial city, a country estate, a 220 V transmission line passed down the street in front of the cottages. According to the regulations, electric wiring, insulated or bare, must not touch trees, branches or bushes. Therefore branches must be trimmed or cut out from time to time. This must be done by the operating personnel responsible for the circuit, since there are safety measures that must be observed. In the incident described, the branches of a birch tree touched a bare wire when the wind blew. During a shower two boys took shelter under the tree. A gust of wind brought the branches against the live wire. Both boys received an electric shock and one of them died.

A number of accidents have been recorded which occurred when uninstructed people have been erecting aials on the roofs of their houses and a guy wire has touched a live wire bringing current to the house. This has usually happened in suburbs or villages. Such accidents are frequent. They have not all had serious consequences but the general conclusion is that when working near transmission wires, whatever the voltage, observe all safety measures. Such work should be done by skilled personnel.

A recent statistical survey of electric traumas published in a Swiss electrical engineering bulletin gives a good idea of this problem in the capitalist countries. It cites figures on accidents involving electricity in England. The figures are unquestionably interesting. Something new and even unexpected is the following. For the time electric traumas on private or-

chards and kitchen gardens have been taken out of the "agriculture" and "miscellaneous" groups and listed separately, although the consumption of electricity on such plots is extremely small.

Fruit-growing has been greatly developed in the Soviet Union. It is necessary that the inspection authorities concerned should draw the attention of fruit-growers and market gardeners to the need for proper operation of electric circuits. Probably there should be a popular, mass edition of the requirements for the operation of electric circuits on individual orchard and garden plots. Accounts of accidents on such plots are published in the special electrical engineering periodicals and consequently seldom come to the notice of the public at large, though it is greatly to the credit of Soviet literature that the need for particular attention to such circuits is stressed. We cite some examples. M. F. Krikunov and F. V. Skvortsov published in the magazine *Vestnik Elektropromyshlennosti* (No. 6, 1957) the results of an inquiry into an accident on an individual orchard plot in which the wife of an electrical engineer was killed by electric shock. The engineer had rigged up an alarm to keep intruders out of the orchard. There was a bell in the room and a spring switch held in the off-position by a cotton thread which ran inside the fence, if the thread was broken or even became slack, the switch closed and the bell began to ring. The wires were under a tension of 12 V. The day before it had rained and everything was damp. In the morning, while the husband was at work, the neighbours heard the bell ringing incessantly and found the wife on the ground without any signs of life. Her neck was touching the 12 V wire. The municipal prosecutor's office appointed a committee of experts to investigate the accident. The committee included highly competent electrical engineers and experienced forensic medical experts. The commission carried out a thorough examination of the signal circuit, paying particular attention to any possibility that the victim had come into contact with the 220 V mains where the insulation was damaged. It was estab-

lished with absolute certainty that this had not happened. From the moment the accident was reported to the end of the inquiry the entire house and especially the signal system was guarded by the militia so that there could be no attempt by anyone to conceal anything. Tested under a potential of 2000 V, the insulation between the transformer proper and its housing was found to be undamaged. The committee was forced to admit that death had been caused by electric shock from current under a potential of only 10 V—something considered extremely rare at that time. According to the committee's conclusion, the victim's neck had come into contact with the switch terminal when she attempted to cross the protected zone. The article concluded with the detailed and comprehensive conclusion of the physicians, explaining this case. In their opinion the physiological mechanism of this fatal trauma consisted in the following. Contact with the live switch terminal had taken place near the carotid sinus, a sensitive nerve centre. The vagus nerve passes close by and the direct action of current on this nerve can cause fatal shock. Evidently that is what happened. The biophysics of this case will be discussed in the next chapter.

In the 'sixties electrified enclosures began to be used in different countries, set up 1-2 metres inside the fence. The inside enclosures carried live wires, and there were warning signs on the fence. These electrified enclosures were publicized in the foreign press, especially in France. Unfortunately there were imitators among fruit-growers. At times this "electrification" was carried out with gross violations of elementary safety regulations. The live wires in the enclosure were connected directly to the 220 V transmission line. During recent years there have been numerous accidents with serious consequences. Among the victims there has not been a single thief or malefactor—the people to suffer have been members of the family or close friends and sometimes even the man himself who contrived the electric barrier.

One is alarmed by some accidents with electricity in every-

day life. Accidents have occurred, the possibility of which was difficult to foresee, even by specialists. For example, electric lighters have begun to be used for lighting gas burners operated from 220 V mains. The wires for the lighters have plastic insulation. It is often necessary to pass the wire over a lighted burner, the flame damages the insulation and subsequently the user may receive a shock. Such accidents are sometimes serious. The most rational way of preventing such traumas is to make provision for lighting the burners in the design of the stove itself. Improving the quality of installation parts and the introduction of plastic bodies for gas stoves have greatly reduced the number of such accidents but other sources of injury have appeared — not many so far but timely attention should be called to them.

When repairing apartments in old houses the open wiring with cord or wire on insulators going along the ceiling and walls is replaced by buried wiring. Installing the new wiring is sometimes done without taking account of the specific features of buried wiring, and the wire and connectors used are not intended for such work. The insulation is not tested under high voltage when repairs are finished, which also leads to electric traumas difficult to foresee. Here is an example. The body of a buried metal connector was in contact with a poorly insulated wire. As a consequence the painted wall was “live”. Accidentally touching the wall and a heating pipe at the same time caused an electric shock that proved fatal. The potential in this case came to 100-150 V. Previously such accidents from faulty wiring were confined to bathrooms and utility rooms. People replacing open wiring by buried wiring must be warned of the need for strict observance of requirements for wire and installation parts to be buried.

Portable standard lamps are now being widely used. Sometimes the outer parts are of plastic, sometimes they are brass or aluminium. When metal parts are used for portable electric equipment, strict watch must be kept on the insulation of the wires. Plastic, porcelain or ceramic entrance bushings may

crack or break and the insulation at such places damages. As a result there are many complaints that people are shocked when they touch metal parts, even when not touching heating or water pipes at the same time. There are also complaints of being shocked by touching the refrigerator in the kitchen.

6. IS A LOW VOLTAGE DANGEROUS?

There is an idea that there is such a thing as a “safe voltage”. Sometimes this is put at 12 V, at other times at 36 V. Of course there is a safe voltage. Sometimes it is much lower than these values, sometimes much higher, depending on conditions and the likelihood of a circuit being formed through a person’s body. The danger of a low voltage is discussed in greater detail in Chapter 7. Here we will only cite a few facts. A trauma caused by a potential of only 12 V was described in the preceding paragraph. That accident occurred in an orchard. Here is another example of a fatal trauma. The body of an electrician, 21 years old, was brought to the morgue. The ambulance physician said death was apparently due to electric trauma, although there were no burns or other injuries on the body. Autopsy revealed distinct asphyxia*, characteristic of electric trauma. According to the ambulance physician and people who had attempted to give first aid before he arrived, there had at first been a thready pulse. Artificial respiration had been started 2-3 minutes after the accident, and according to the doctor it had been done competently. The doctor had attempted to revive the victim on the spot and had administered a strong vasodilator. Along with artificial respiration, the heart muscle had been massaged by appropriate pressure on the chest. It had been impossible to save the victim’s life.

The accident had happened under the following circumstances. A commission was inspecting the fixed wiring of electric

* Asphyxia (suffocation) — death caused by the stoppage of respiration followed by stoppage of cardiac activity.

equipment in a basement, for its acceptance. To facilitate the commission's work a wire carrying a 12 V portable lamp was let down from a 220/12 V step-down transformer. Except for a small section at the base of the lamp, the wire from the transformer was enclosed in a rubber hose which was in good condition. The wire proved to be too short so the members of the commission inspected the area with 6 V torches. The coiled wire from the transformer together with the lamp was hung on the iron railing of the stairway leading to the basement. When the inspection was finished, electrician K., his left hand on the iron railing, reached for the coil of rope to take it upstairs. The moment the back of his hand touched the wire he let out a strange, throaty cry, so the others said, and slumped over. The members of the commission standing beside him tried to hold him up and were shocked. When K. was freed from the coil of wire, he was taken upstairs and immediately given first aid. As was already said, this was unsuccessful. A thorough examination of the insulation between the windings of the transformer and between the 220 V winding and the housing was in excellent condition. When the wire let down into the basement was examined it was found that one of the strands was carelessly insulated. There were bare spots where the wire from the transformer was connected to the wire of the lamp, and anyone picking up the lamp could touch them. The second wire of the transformer was grounded. The committee of experts examined other possibilities, however unlikely, of the wire K. touched being under high voltage, and rejected them all. While taking precautionary measures, the committee reproduced the situation obtaining before the accident and the moment of the accident itself, after which they pronounced their unanimous conclusion—the man had been killed by a potential of 12 B. The members of the committee called attention to the fact that the victim could have touched the places where the insulation was damaged with the back of his hand.

A woman fitter at a laboratory was killed in approximately

the same conditions, that is, by touching a bare wire with the back of her hand. The committee of experts concluded that the potential responsible for her death did not exceed 12 V.

Fatal traumas from potentials of 10-24 V are described in the literature. Until recently such occurrences were considered extremely rare exceptions, since problems of electrical safety engineering were largely solved by lowering voltages wherever possible, particularly for portable lighting. There are grounds for doing so. It cannot be denied that the probability of serious consequences when the voltage is low is less than when it is 220 V. But a deeper analysis of electric traumas shows that such cases are not so rare. The point is that usually when analyzing electric traumas it is the voltage of the faulty circuit or installation causing the accident that is taken into consideration and not the actual voltage from which the victim died. Actually these values are by no means the same. They are identical only if there is two-pole contact with current-carrying parts, but in 80% of electric traumas there is single-pole contact and the resistances of footwear, clothes, floor, and at times structural parts of equipment are connected in series with the victim's body. In the case described above, in which two boys were standing under a tree whose branches touched an electric wire, the resistance was the surface resistance of the tree.

The resistance of footwear, clothes, floor and other objects in the circuit passing through a person's body is very high, sometimes tens of thousands of ohms. Even damp footwear at times has a resistance of several thousand ohms. Thus the voltage of an installation can be two to four times the voltage causing a fatal trauma. According to data gathered by the Leningrad Institute of Labour Protection 60-70% of traumas recorded are in the single-pole class. Even the most cautious conclusion puts the number of victims from low voltages quite high, and this is confirmed by figures for deaths from a welding potential, which is only 65 V.

The fact that death can be caused by 12 and 36 V alternating current would seem at first sight to be at variance with the value of 100 mA considered in electrical engineering to be the lower limit of dangerous current. At the low voltages mentioned the current causing serious trauma or death is less than a milliampere, even in the most unfavourable conditions for the victim.

Why the discrepancy? The point is that when setting the value of current dangerous to man, only fibrillation is taken into consideration. The mechanism of this disturbance has been established by numerous experiments on animals. But data on electric traumas in animals is contrary to data on many electric traumas from low potentials leading to death in people. This contradiction can be explained by the assumption that the mechanism of electric trauma may be different and consequently the current dangerous for man may be different. The validity of this explanation is borne out by the instances of death from low voltages cited and also by other considerations which will be taken up in the next chapter.

7. ONE HUNDRED AND TEN KV POWER TRANSMISSION LINE IN THE CITY AND THE ELECTRIC SAFETY OF MEDICAL INSTRUMENTS

Consumers of electric energy are divided into different groups according to the reliability of supply required and according to the electric safety of their electric installations. There are consumers for whom a power failure is not dangerous and there are others for whom a power failure means an accident or serious material losses. For example, if the power being supplied to an electric melting furnace is cut off, the metal will be rejected and the furnace seriously damaged. Other examples could be named. For this group of consumers measures must be taken to prevent even short power failures and

this is possible. When the introduction of 110 kV power lines was under consideration the question arose as to whether it would be possible to transmit power of that voltage directly to consumers through thickly populated districts of Moscow. It was feared that wires might break and people could be killed. The chairman at a conference where it was being decided whether or not such a power line could pass through the city said that it was absolutely necessary for a 110 kV power line to pass through the city and such wire had to be used and it had to be secured in such a way that no breaks were possible. Optimal versions of constructing a highly reliable power line through the city were worked out and implemented. The 110 kV power line was operated for scores of years without a single accident. No one is surprised now at the 220 kV which passes through busy streets directly to the power departments of factories. "Wires must not break" is something that must be remembered when designing and operating medical instruments. The use of electrical apparatus in medicine has greatly increased. Complex electrical measuring systems and other instruments are set up beside the patient's bed. Reanimation departments and operating rooms can vie with any industrial or educational laboratory in the electrical engineering line when the extent of their electronic apparatus is considered. Electricity can be dangerous but hazards can be eliminated by rational techniques, rational operation of electrical equipment.

Let us return to the statistics of electric traumas and consideration of the danger of possible injury from electric current when medical instruments are being used. Statistics give great satisfaction. The increase in the number of electric medical instruments and the increase in the capacity of electric medical installations has not been accompanied by a corresponding increase in the number of electric traumas. But there have been accidents and there still are. Although the number is not great it is increasing. A careful analysis of each injury from electric current in a medical institution shows that it could have been avoided. Electric traumas in hospitals, clinics, the-

rapeutic departments of sanatoriums, etc., can be divided into two groups. The first group includes electric traumas similar to those in everyday life. Their source is faulty insulation in lighting fixtures, electric systems, sockets, etc. Statistics show that such traumas are relatively less frequent than in household and municipal circuits. This is evidence of the great feeling of responsibility in the engineering sectors of medical institutions, which work in difficult conditions. The second group is made up of traumas which occur while servicing medical apparatus. Both groups of traumas can and must be prevented. Some electric traumas have been described in this book. It would be well to generalize the typical traumas.

Buried wiring is used everywhere. In household and municipal circuits this has sharply reduced the number of electric traumas caused by faulty insulation of interior circuits. However, they could be eliminated completely if requirements for the installation and acceptance of circuits for operation were raised along with requirements for the supervision of operation. What has been said about the causes of such electric traumas also applies to circuits in medical institutions, although there are some specific features. Washbowls with running water are usually installed in wards, particularly in modern hospitals. Damage to the earthing or failure to comply with instructions for earthing washbowls may bring it about that there is a potential between the tap and the floor or wall if water pipes are used for earthing electric equipment even if it is on a different floor. There can also be a potential between the tap and the floor, wall or ceiling if the insulation is damaged in the distributing boxes or connectors of the buried lighting system. The insulation can be damaged during installation of the electrical equipment circuits and during their operation. It is extremely difficult to detect faults. Experience has shown that the best way to prevent insulation faults is to substantially raise the specifications for insulating such circuits. The minimum resistance of the insulation on the section of the circuit from the safety device to electric installation or

installations could be set at 10 megohms. The resistance should be measured with a megger or some other instrument under a potential of at least 1000 V. A resistance of 10 megohms considerably exceeds the usual requirements for circuits up to 1000 V laid down in the specifications, but this is justified. In such tests an insulation resistance less than 10 megohms will be found only at places where branch lines are connected and there are faults in the insulation or signs of a fault are just beginning to appear. As a rule this is due to careless "cutting in". It is not an easy matter to find such spots where the resistance of the insulation has fallen but it must be done. This would be facilitated by the use of radio engineering methods as is done in circuits with a voltage over 1000 V. It is not practised as yet on low-voltage circuits. Walking on floors covered with plastic tiles or linoleum may produce static charges on the body, and on touching a metal tap there may be a painful discharge; this will be prevented if the tap handle is porcelain.

It is clear how to reduce the number of electric traumas associated with the mains, but it is considerably more difficult to solve problems of accident prevention involving operation of the medical instruments. In many electrodiagnostic and electro-therapeutic procedures the patient's body is an element in the electric circuit, since it is impossible to obtain the electrophysical characteristics of the human body, a unique source of biological information, in any other way. The methods used are of two types. In the first method, the source of information is bioelectric activity, and this can be called a method with passive electrodes. Electrocardiography is an example. There are also methods with active electrodes, such as iontophoresis and rheography. The use of active electrodes makes it necessary to introduce a number of safety measures—neglecting to do this can lead to regrettable consequences. At a certain clinic a rheogram was being recorded to assess the functions of external respiration. The rheogram was being recorded with an ordinary electric recorder in ink on paper tape. The measuring system consisted of three units—the recorder, a

high-frequency generator, and a frequency converter. The housings of the three units were earthed in series, i.e. were connected one to the other with a flexible cable. The examinee lay on a metal bed and was holding to the head of the bed with one hand, no attention being paid to this at the time. The framework of the bed was earthed. As a result of faulty insulation in the recording instrument, a potential was produced on one of the electrodes on the examinee's body. The man cried out: "It's shocked me" and rolled over on his side unconscious. Competent measures were taken immediately to revive the victim — the heart was massaged and stimulants were given but everything was in vain. The ECG showed that the heart beat had been restored for 3-4 cycles, after which fibrillation set in, ending in death. Using an electric defibrillator had no effect. The committee of experts modelled the layout of the accident and came to the conclusion that death had been caused by current under a tension of 28 V. Potential had been produced on the electrode by faulty insulation of the recorder, while there had been increased resistance between the common earthing cable and the earthing wiring. Violations of the regulations were also noted: there had been no systematic testing of the resistance of insulation in medical instruments; the instruments had not been properly earthed and the condition of the earthing wiring had not been checked. Had it not been for the violations of the regulations, the man would not have lost his life.

One is greatly alarmed at the enthusiasm for electropuncture instead of acupuncture that has lately appeared. Home-made instruments are beginning to be used by people who are not sufficiently acquainted with ordinary acupuncture. Injuries with serious consequences have been recorded, and those guilty have been severely punished. Anyone, whatever his rank, whatever his qualification, who uses or permits the use of medical instruments that have not been approved by the Ministry of Health will be severely punished. It must not be forgotten that in the Soviet Union any new instrument must undergo comprehensive clinical trials at special medical instrument institutes.

CHAPTER SEVEN

Biophysics of Electric Injury

1. FUNDAMENTALS FOR STUDY

In the second chapter we considered the specific features of electrical conductivity in inanimate and animate matter and pointed out the complexity of conduction by organic semiconductors and insulators, living organisms and especially, man, and also how little is known, as yet, about electric conduction inherent in the living organism. Consequently the discrepancies that occur in determining dangerous voltages are not to be wondered at, nor the discrepancies obtained between results in experiments carried out on animals and the reactions observed in man.

There are grounds for the following conclusion: it is difficult to kill a person with electric current, but accidentally to die from electric current is very simple. It rests on solid facts: the easy and instantaneous death from a small voltage, not exceeding the voltage of the illuminating mains, and the lengthy and agonizing death of a person executed in the electric chair at a voltage of 1200-2000 V.

What is the explanation? The mechanism of the action of electricity on such relatively simple substances as metals, solutions and crystals differs. In this case no one is surprised if there is no immediate answer to the question: "Is this material safe for wiring?" The electrician will ask: "Do you mean for a load of 10 amperes, or some other?" To answer that question one must know what material the conductor is made of, its cross-section and how it is to be mounted. If that infor-

mation is available, it can be said quite accurately whether or not the given wire will conduct a certain current without any danger of failure. What has been said also applies in principle to a conductor possessing ionic conductivity. One must know the chemical composition of the electrolyte, the dimensions of the electrodes, and the voltage. If what has been said is true of metals and solutions, it is all the more true of man. People once judged of the degree of danger threatening that most complex of complex natural objects, man, by two factors at best, the voltage and the current, assuming that the danger increased in direct proportion to increases in the values of these two factors.

This assumption persisted so long as electricians and physicists were out of touch with pathophysiologists, biologists and physicians. In the first chapter we noted the broad and justified interest specialists in diverse technical fields now show in biology, biophysics and biochemistry. Overlapping sciences on the border between technology and the natural sciences are today rapidly developing, enriching both technology and biology.

We continue the analogy. Failure of an ordinary copper conductor can be caused by the following: (a) burning-out because of excessive current density; (b) breaking, due to electrodynamic stresses; (c) oxidation—corrosion of contacts, etc. Death due to injury by electric current may also result from a number of causes: (a) fibrillation due to the direct passage of current of sufficient strength through the myocardium; (b) stoppage of respiration; c) shock. Each of these causes depends on the value of the current, the value of the voltage and the duration of the electric circuit through the body.

Thus, the first and basic conclusion to be drawn from a general consideration is that it is impossible to name a definite safe value of current or voltage. This general conclusion is borne out by other information provided by an analysis of accidents. A unique case in which an electrician was in a circuit with a tension of several thousand volts and a current

of 7-8 amperes passed through his body and was not killed is described in V.E. Manoilov's book *Osnovy electrobezopasnosti* (Fundamentals of Electric Safety) (Energiya Publishing House, 1976). Data on the voltage and amperage were obtained from the tape of the accident oscillograph which was automatically cut in when there were single-pole failures of the insulation in an electric circuit of 6.0 kV. The man was standing on an oil circuit breaker, and holding on to the 6.0 kV busbar when current was fed to the busbar by mistake. The man's hands were seriously burned but he recovered and eventually resumed work in a limited capacity.

Cases are known in which people having to do with electricity by occupation have been in a circuit of still greater voltage, have received burns of one degree or another, and have fully recovered to continue their work as before.

So there is no explicit answer to the question "What current is dangerous?"

When the results of experiments on animals are compared with an analysis of accidents that have happened to people, one comes to the conclusion that in an electric circuit man is a special type of "conductor", differing in its properties, in its reaction to electric current, from any organic or inorganic element of an electric circuit, and also from any species of animals. In animals there is not such a difference in the reaction to a high voltage and a low voltage, as in man, and consequently experimental data obtained in studies of electric injuries in animals can only be applied to man with great caution.

2. THE DISPUTE CONTINUES

Thus, an analysis of deaths from low voltages and "favourable" terminations in cases of high voltage leads to the logical conclusion that man's reaction to electric current is very diversified, that in some cases there is a strange sensitivity to weak currents. This shows the necessity of further study to

determine what is injured first—the cardiovascular system as a whole, the myocardium or the respiratory system. Determination of the system, injury to which marks the beginning of the body's serious reaction to electric current is important in increasing medical and biological knowledge but that is not all. If it is known where the injury begins to develop (or let us say where it most often begins)—the circulatory system, the respiratory system or some other system—the fight to save the victim's health or even his life can be made more expedient. This can be explained with an example.

Disturbance of cardiac activity because of injury by electric current in a man who is operating a manufacturing unit may have serious consequences not only for the victim. Automatic transfer of control (if only temporary) to an automatic controller or to another operative can limit a possible catastrophe, and automatically bringing into action reanimation facilities, such as electric stimulation of the heart, can save the victim.

When studies of industrial electric traumas first began it was thought that it was the respiratory system that was injured first and foremost. Autopsies in cases of death from electric shock indicated that the victims had died of asphyxia (suffocation). This point of view was maintained by Jellinek, d'Arsonval and others who had investigated injuries by current at all stages. But this opinion was considerably shaken by experimental study of electric injury in dogs in which it was found that the predominant cause of death was disturbance of cardiac activity. To cause the death of a dog by the stoppage of respiration, the electrodes, or at least one of them, had to be fixed to the ears or ear. To this should be added that in individual cases ("individual" must be emphasized) the cause of death in people, as shown by the post-mortem, was direct disturbance of cardiac activity.

At the Seventh International Congress on Industrial Traumatism held in 1935, Stassen, an outstanding pathophysiologist, proposed that fatal injuries should be classified as blue

(with primary stoppage of respiration) and white (with primary stoppage of the heart). Some investigators assume that there can be simultaneous disturbance of cardiac activity and stoppage of respiration.

During the next stage diverse mass experimental studies of electric injuries in animals were carried out in the Soviet Union and abroad. As a rule, the results indicated a probability of death from stopping of the heart due to fibrillation. The position of the "fibrillationists" was shaken by the data of comprehensive, more thorough analysis of accidents in people and doubts as to the possibility of extending to man data obtained in experiments on animals. The evidence that death results from stoppage of respiration is especially important. In this connection the work of I.K. Mishchenko (Academy of Sciences, Kirghiz SSR) is noteworthy. He demonstrated that a current of 250 mA was necessary in the electric circuit for fibrillation to begin in males, and a current of 220 mA in females. These data are in line with those of the German physiologists, Koeppen and Panse. According to the unanimous opinion of some researchers, 70–80% of fatal accidents occur in circuits with a tension of 220 V. But according to Mishchenko's data fatal injury from fibrillation of the heart in such circuits is impossible in general. A simple calculation proves this. If it is assumed that at the moment of the accident the entire resistance in the circuit is the resistance of the victim's body, then at a tension of 220 V, a current of 200 mA in the circuit through the victim's body is impossible. Even a minimal resistance will reduce the current to tenths of a milliampere. The evidence is weighty but it has not ended the argument. The dispute about which is injured first, the heart or respiration, continues.

Fresh data on the electronic conduction of biopolymers shows that there is another possibility of injury—through the central nervous system.

3. MAN—A SELF-REGULATING SYSTEM

Results of investigations into the electronic conduction of complex polymers and biopolymers throw fresh light on the dispute: respiration or the heart. Irrespective of the degree of development of the protracted dispute it must be pointed out that there is a certain arbitrariness about it. In normal conditions (“normal” should be underlined) the respiratory and circulatory systems comprise a single functional unit, a closed system with automatic regulation. Suffice it to cite the fact that the heart receives stimulating impulses directly through the respiratory centre of the nervous system, and the latter, like the respiratory system as a whole, can work and fulfil its function only when there is a normal supply of blood along the entire tract of oxygen transfer.

A person becomes part of an electric circuit, and there is local, or possibly general, absorption of electric energy. The functions of the usually precisely operating unit are disturbed. If even a single element of the functional unit is put out of action, automatic regulation of the circulatory system, the most important of the life support systems, will be upset. No matter in what element of the general system impairment occurs, it will come to a head in the heart and the latter's vitally important pumping function will be upset. With the ceasing of the heart beat, the action of injurious factors comes to an end and death ensues.

The work of all the complex systems, beginning with the electric system and ending with the biological is subordinated to a definite rhythm—the sequence of interconnected processes.

In cases of injury there can be two terminations: the functions of the general system of self-regulation that have been impaired by injury to any one of its elements may be restored by falling back on reserves or by some other method. The injured element turns to be blocked and the system's automatic self-regulation restores its functions. But there can be a differ-

ent termination when within the system there is no reserve of self-regulation, the system is not restored and self-regulation ceases. The functional system ceases to exist. The question arises: can the self-regulating system be restored by acting on it externally? Sometimes it is possible, sometimes not. It depends on many circumstances.

Any injury, including electric injury, disturbs the rhythm of biological processes which are strictly interconnected by the transformation of energy (generally speaking), and temporally. In conditions of normal vital activity some processes are synchronized, some are cophasal and some are in the antiphase or take place with a definite sequence of phases. During vital activity in definite conditions, organs and tissues are capable of interregulation.

Self-regulation means that all temporal, frequency and amplitude quantitative relationships in the transformation of energy must be observed. When relationships are optimal for normal vital activity, the work of the heart is an ideal example of rhythmic operation: the strictly phased auricles contract before the ventricles. If the phases were not stepped, the upper half of the heart would not be able to pump blood into the lower half and the latter would not be able to propel it through the arteries. The temporal shifts in the work of the auricles and ventricles was shown in Chapter Five when the electrocardiogram was described.

Returning once more to the curve of the heart's electric activity, it should be noted that a change in the temporal, frequency and amplitude characteristics of the ECG indicates disturbances in vital activity of one kind or another but usually serious. Let us assume that the rhythm of the work of the parts of the heart is deranged and the auricles and ventricles begin to contract simultaneously. Circulation of the blood will be seriously disturbed, a condition called auricular block, and a fatal termination is inevitable. But another arrhythmia is possible—fibrillation—which can be overcome by external means, particularly by use of the defibrillator des-

cribed in Chapter Two. Derangement of the cardiac rhythm can be caused by disorders in the respiratory system or in the vessels. Without dwelling on other disturbances of the system of automatic regulation of cardiac activity, one thing should be emphasized: the heart and the entire blood-supply system must work as a single whole, and without fail, with the phase, temporal, frequency and amplitude characteristics required for precise automatic regulation of vital activity. Otherwise the heart, a determining element in this automatic system, will be put out of action.

So far we have considered the performing elements of the system which automatically regulates the body's vital activities. Their activity is indissolubly associated with the system of automatic control whose functions are fulfilled by the nervous system. Impairment and disturbance of this system can lead to disturbance of the circulatory and respiratory systems. In its complexity the biological control system has no analogues even in the most complex mathematical machines. Electric current can damage it too, and the result will be the same—stoppage of the heart.

The part played by the nervous system in the termination of electric injury is discussed in the following section.

4. SOMETHING UNEXPECTED

The following experiment was carried out at several engineering plants. Absolutely all complaints of electric shock were recorded at the power department. While putting to rights the faulty insulation, the conditions in which the person was shocked were established, although in most cases there were no consequences. The data obtained were compared with the statistics and analysis of accidents with fatal outcome. It was found that in 70% of the cases of electric shock without injury, the electric circuit was from the palm of the hand to the feet or from palm to palm. Such circuits were only natural for the work being done at the time. In fatal accidents the elec-

tric circuit, as a rule, passed through different parts of the body. In 8% of fatal accidents involving 220 V mains at work and at home, the circuit began through the back of the hand. It seemed that there must be parts of the body especially sensitive to electric current. That proved to be the case.

Back at the end of the 'thirties N.B. Poznanskaya while studying the electric conduction of the body discovered precisely delimited areas of the body with unusually low conductivity. Poznanskaya's observations were confirmed by investigations of accidents which revealed the significance of the current's "path" through the body, and also by the results of investigations carried out by the present author. There are grounds for assuming that there are areas of the body particularly sensitive to current or electric fields—areas that are converters of primary information, signalling the presence of the natural electric field inherent in the terrestrial atmosphere. The areas of the body vulnerable to electric current, in addition to the back of the hand already mentioned, are neck, temples, back and shoulders. These converters can be called electroreceptors. We cite some examples showing the great influence of the nervous system on the outcome of electric injury.

At an enterprise under construction steel reinforcement was being welded. The insulation on one of the welding machines was damaged, thus feeding the 220 V mains' tension to the low-voltage welding circuit. Three of the workers felt an electric shock. One of them said: "We've got to tell the foreman", and set off through the grounds of the project to the building where the foreman was. He went up the stairs to the first floor where the foreman had his office, told him what had happened, sat down in a chair and died. The autopsy showed he had died of asphyxia. No direct injury to the heart muscle or the vascular system was discovered. The circumstances of the case and the findings of the autopsy did not exclude death from electric shock, particularly since there were characteristic minute burns on the victim's body. At least 25-30 minu-

tes had passed from the moment of the shock to the worker's death.

Another example. A crane was being handed over. The foreman climbed up to the cabin assuming that the current had not been turned on. With his left hand he touched the terminals of a panel being installed, which it turned out were live. Sharply reprimanding the electrician in the cabin for cutting in 220 V without informing the power department, he climbed back down to the ground. Staggering for some reason, he took a few steps and fell. He could not be saved. Some 10-15 minutes had passed from the moment he was shocked until he died. The results of the postmortem were the same as in the preceding example though the marks on the body were more distinct. Yet another example. A worker was shocked by contact with 380/220 V mains. Apparently the actual tension on his body was 150-180 V since the circuit was between his hand and his feet, and he was wearing leather boots, though they were damp. He lost consciousness from the shock and stopped breathing. The other workers around immediately began giving him competent artificial respiration and he soon came to, complaining only of weakness and a heavy feeling in his head. There was a burn on one finger. He was taken to the medical station on a stretcher, where besides other measures the doctor gave him an intramuscular injection of a vasodilator. After two hours the victim said he felt all right except for being weak. The doctor wrote him a sick-leave document and told him to go home, advising him to call a doctor if there were any symptoms of indisposition. The man began to dress and at that moment died. The postmortem diagnosis was heart failure.

And now, the last example. A technician on duty was telling the man who had come to relieve him what was cut in and what was not. Saying "This bus, here, is 10 kilovolts", he put his hand on it. From the electric arc the technician received such serious burns that both legs and his right hand had to be amputated. After being in hospital for a month and a half the victim began to recover. The stumps of his legs and hand were

in the final stage of healing. The physicians attending him had no fear for his life and his death on the eve of his discharge was completely unexpected. Highly qualified pathologists performed the autopsy and the tentative diagnosis of the immediate cause of death was heart failure.

In the light of modern conceptions of the action of electric current, it can be assumed that in all the cases described above, one of the basic causes of death could have been impairment of cerebral circulation. Since as a rule autopsies were performed a day after death it was very difficult to establish the exact cause—impairment of cerebral circulation. The practical conclusion: in any case of electric injury, but especially if accompanied by disturbance of circulation, it is absolutely necessary to consult a neuropathologist in addition to treatment of the trauma by a surgeon.

5. DANGER!

A large shipyard. A big gantry crane covering a large expanse in its travel, and on the crane a placard with the representation of a person's eyes. The eyes are painted in such a way that no matter where you are, within reach of the crane, they seem to be watching you. Under the picture, the word "Danger!". It is interesting to note that at this shipyard there are fewer accidents than at other similar enterprises. Being careful when operating machines or when one is close to machinery is of great importance in general for efficient, accident-free operation. But in electrical engineering, being careful, being collected, creates a special, protective reaction.

In the 'twenties, Jellinek, who by that time had taken part in investigations into the circumstances of hundreds of deaths from electric shock pointed out that differences between the central nervous systems of man and animals made it impossible exactly to model electric injury in man on electric injury in animals. At that time Jellinek had probably already come close to understanding why it was difficult to correlate data ob-

tained in experiments on animals with those obtained by careful instrumental analysis of electric injuries in people. It was then, in 1927, that he first stressed the importance of attention as a factor lessening the severity of electric injury. He wrote: "The principal peculiarity of electric injury is that our strained attention, our firm will is capable of weakening the action of electric current and sometimes even overcoming it. The crushing force of a falling beam or an explosion cannot be weakened by courage and brave self-control, but it is quite possible in regard to the effect of an electric shock if it occurs when the attention is strained... Actually a person who hears a shot without seeing the man with the gun may die from shock but a person who is looking at the man who shoots or is himself shooting is not subject to shock".* Jellinek is speaking of the self-control of a person expecting something about to happen or engaged in work requiring strict attention. He continues: "Attention is a factor which plays an extremely important role, perhaps a decisive role... Usually nothing happens to a person in a state of strained attention... He sets his attention like a shield against the terrible, impending moment". Similar convictions have found expression in the sayings of many peoples. The English say "Forewarned is forearmed". The French have a similar saying, "A person warned is equal to two".

This assertion holds true, for the most part, for injuries from electric current of 220-380 V. At higher voltages the injury is usually from burns caused by the arc. In this respect there are grounds for assuming that the severity of the outcome increases practically in direct proportion to the voltage.

Jellinek did not limit himself to conclusions drawn from investigations of accidents. He carried out experiments showing that attention was also a factor in animals. The test animals

* Jellinek, S., *elektrische Unfall* (Accidents from Electricity), Vien, 1925.

were cats. Electrodes were secured to the animals' bellies; wires from the electrodes led to a source of current. After allowing sufficient time for the animals to become accustomed to the wires, in some cases as much as 24 hours, the current was turned on. The animals were killed instantaneously by 120-220 V. When animals were secured on their backs as was usually done when investigating experimental electric injury, or were suspended by straps round their bodies, as in the latest experiments of the German scientist, Osypka, the animals did not die immediately from the same voltages. To kill them in these conditions required 20-30 minutes or the tension had to be increased to several kilovolts. Similar experiments were carried out on other animals with the same results. However, it should be noted that the significance of the attention factor has not as yet been taken sufficiently into account in electric safety measures. But one is confident that new views on the electric conduction of living tissue and further study of the nature of the electric activity of the human body will reveal the biophysics of electric injury in man, which will be taken into account when protective measures against electric current are worked out.

But even now a hypothesis can be voiced. The attention factor undoubtedly increases the supply of blood to the central nervous system and increases oxygen consumption which in turn brings about an increase in the number of charge carriers (electrons) in biochemical metabolic reactions. The increased or in some way intensified stream of charge carriers is not so easily disturbed by an impulse of weak current, such as is involved in injury by low voltages. It is of course more difficult to disrupt the biological system of automatic regulation when there is an increased blood supply to the nervous system. This is evidently the key to understanding the development of the injury and the occurrence of death a considerable time after an electric shock.

6. ELECTRICITY KILLS ANIMALS AS WELL AS PEOPLE

It has long been known that animals are killed when struck by lightning. Cases are described in the literature in which 2000 sheep were killed during a thunderstorm, and during another storm, about 1000 sheep. Horses and cows are also killed by lightning. In one thunderstorm 126 cows in a herd of 152 head were killed.

When high-tension power lines of 110 kV were first introduced reports began to appear of cattle in the field being killed by electric current. This was usually where high-tension wires had broken, and death was caused by ground potential. This can be dangerous a hundred metres from the fallen wire, the potential in respect to the earth being 50 kV and higher. Cases of animals being killed by short circuits near badly insulated earthing cables have also been recorded. The adoption of more stringent requirements to ensure reliability in the operation of power transmission lines, along with the application of more effective measures for protection against lightning has substantially reduced the breaking of wires, and consequently greatly reduced the number of animals killed by ground potential gradient. Protective measures at open substations are intended to keep the ground potential below the permissible level of 150 V, which is considered safe for people. In many cases animals are killed by such a voltage.

Extensive electrification has been accompanied by the growing use of electric power in all sectors of agriculture. This trend has been particularly marked in animal husbandry and poultry raising where farms are becoming industrial enterprises with complex electrical equipment.

The rapid development of agricultural power engineering has outstripped the training of operating personnel, and also the manufacture of specialized equipment and cables required in agriculture. The point is that electrical equipment at cattle, dairy and poultry farms is installed in damp buildings where

the floors, as a rule, are conducting. The potential relative to the ground is 220 V.

It is considerably more difficult to ensure reliable operation of electric installations at farms than at industrial enterprises. A number of breakdowns of electric installations at farms have been reported involving losses of more than 10 animals. As a rule animals are killed in circumstances similar to those in which people are killed. This makes an analysis of electric injury in animals instructive.

Protective organizational and technical measures taken after each accident to improve the installation and operation of power lines and electrical equipment increase reliability and make the loss of animals less likely, but this should be done without waiting for accidents to happen.

V.P. Sakulin has made an interesting and very useful analysis of electric traumatism in animals. Electric injury in animals differs from that in people. In the mechanism of action of electric current it is simpler and assists in clarifying conceptions of the dangerous action of electric current on man. The first and probably the principal difference is the following. Practically speaking, there are only three ways in which an electric circuit is formed through an animal's body: foot—foot, feet—feet and muzzle—feet. In animals in a house tethered with a chain, there is an additional circuit—one through the neck. However, an animal's hair is a good insulator and limits the passage of electric current through this additional circuit. Investigations have shown that this circuit does not increase the danger. The second difference in electric injury in animals as compared to electric injury in people is that in animals there is a possibility of injury with a smaller specific ground potential gradient (the ground potential gradient per meter). This is explained by the fact that the distance between the legs of a large animal is almost twice the length of a man's stride. The third particularity is that electric injury in animals always occurs in the open air or in houses, as a rule unheated, where the animals stand on a conducting floor.

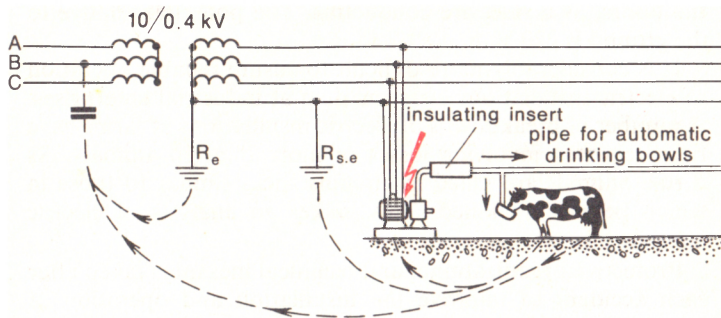


Fig. 21. Diagram of injury to an animal caused by breakdown of insulation of wire while resistance of second earth is high

R_e —resistance of main earth; $R_{s.e}$ —resistance of second earth

The diagram in Fig. 21 (taken from V.P. Sakulin's analysis) illustrates electric injury to an animal at a dairy farm. This is caused by the breakdown of the insulation of the phase wire while the resistance of the second earth is relatively high. This often occurs. In industrial buildings there are many natural earths, such as metal structures, pipe lines, water pipes, etc., but in farm buildings there are much fewer.

We give two typical examples of possible electric injury in animals. At cattle and dairy farms automatic watering systems with motor-driven pumps are widely used. When installation is careless and a constant watch is not kept on the condition of the insulation, the latter may be damaged. As a result the water pipe is live and so is the water since it is a conductor. If a cow or any other animal touches the water, an electric circuit will be formed through its body and it will be killed. At some farms there have been cases when as many as 30 animals were killed in this way.

Another example. The operating personnel do not pay enough attention to the condition of the insulation of wires and cables where they pass through walls. For one reason or

another the insulation may be damaged. Usually this results from some defect in the insulation formed during installation. Subsequently the wall begins to carry current, and feeding troughs as well. An animal touching the trough will be shocked and die.

Measures to prevent the loss of animals are simple: careful installation of all electric equipment, regular checking of the insulation with a megger (an instrument for measuring the resistance of insulation) and the replacement of sections of the wiring or electric installations in which a lowering of the insulation resistance is discovered.

The analysis of electric injury in animals, causing their death, has given unexpected results which are useful for understanding the mechanism of action of electric current.

Data cited by Soviet and foreign authors agree on the value of lethal current for animals, unlike the contradictory data regarding lethal current in man. Lethal current: for calves, 0.2-0.3 A; cows, 0.3-0.4 A; sheep and swine, 0.15-0.20 A. Lethal tension, 30-40 V. The close agreement of these data is explained by the fact that in animals the current acts directly on the heart, causing fibrillation, whereas in people the injury is often associated to a greater or less degree with serious disturbance of cerebral circulation.

The operation of electrified agricultural equipment requires serious attention. Special electric installations and special wire for power lines are necessary. The population must be explained the specific features of the action of electric current and the principal protective measures to be taken. Electric traumatism in animals like electric traumatism in people in agricultural production can and must be eliminated.

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